Environmental Geoindicators, Their Significance, Pollution Assessment, Determination of Source Areas and Remedial Measures in Dal Lake Catchment Areas, J&K

ABSTRACT

THESIS
SUBMITTED FOR THE AWARD OF THE DEGREE OF
Doctor of Philosophy
IN
GEOLOGY

BY
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DEPARTMENT OF GEOLOGY
ALIGARH MUSLIM UNIVERSITY
ALIGARH (INDIA)

2002

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ABSTRACT

In a geological prospective lakes are regarded as temporary waterbodies on the land surface, formed generally by some drastic geological events, volcanism, earthquake or glaciation and constitute only about 1% of the earths continental surface and contain < 0.02% of total hydrospheric water. Inspite of this meagre figure, lakes are of great geological, geochemical and geo-limnological significance.

Most of the valley lakes in the study area are fed by melt waters from glacial lakes of the Himalaya including Dal Lake, which is the urban valley lake of fluviatile origin, is situated at an altitude of 1583m between $34^{0}6'$-$34^{0}10'$N latitude and $74^{0}50'$-$74^{0}54'$E longitude in the heart of the Kashmir valley on the north east of the state summer capital Srinagar. The total surface area of the lake is about 11.45 Km^2 comprising of Boddal, Gagribal, Nagin and Hazratbal basin, which is located in the north of the Dal Lake and is fed by various inflow channels mainly Telbal Nalla that drains the whole catchment area.

In the study area the sediments of the whole inflow channel contained very high proportion of silt (63.71 %), moderate proportion of clay (24.25%) and very low proportion of sand (12.13%). The sediments of Hazratbal basin over all, recorded 23.35% sand, 55.87% silt and 20.77% clay. The grain size distribution of the whole Boddal basin showed some similarity with the inflow channel, with sand, silt and clay constituting 9.97%, 63.75% and 26.27% respectively. However, the particle size distributional pattern of sediment grains of Gagribal basin showed some degree of similarity with that of Hazratbal basin as the sand silt and clay were recorded in a ratio of 21.82: 63.30:14.87 and the Nagin basin, like inflow channel recorded high proportion of silt (66.7%), moderate proportion of clay (21.0%) and very low proportion of sand (12.5%).

Overall, the grain size values of the lake sediments vary from 3.2ϕ to 4.6ϕ. The highest values (4.3ϕ to 4.6ϕ) are recorded in inflow channel while the lowest values (3.2ϕ to 3.6ϕ) are recorded in Gagribal basin. In the rest of

the basins of the Dal Lake, the mean grain size is around 4.0ϕ. Standard deviation values in the sediments of Dal Lake ranged from 1.9 ϕ to 3.0ϕ , higher values being conspicuous from the Hazratbal basin(3.0ϕ to 3.1ϕ) and lower values (1.9ϕ to 2.1ϕ) from inflow channel and the rest of the basins i.e., Boddal. (2.0ϕ to 2.2ϕ) and both Gagribal and Nagin (2.1ϕ to 2.3ϕ) basin showed moderate values of standard deviation. It is clear from the values of standard deviation that all the sediments collected from the different basins are poorly sorted. The poorly sorted nature of the sediments is apparently due to the mixing of the modern sediments with relict sediments in the complex hydrological flow system of Dal Lake.

Skewness values (SK_1) in the sediments of Dal Lake varied between – 0.29ϕ to - 0.04ϕ. The sediments are grouped into near symmetrical with skewness values of around – 0.07ϕ to – 0.04ϕ recorded from Hazratbal and Gagribal basins and coarse skewed with skewness values from -.0.29ϕ to -.0.12ϕ recorded from Boddal, Nagin and inflow channel. The coarsely skewed sediments have developed relatively under high energic condition areas near the mouths of the inflow streams while near symmetrically skewed sediments have developed under relatively low energic conditions. The kurtosis (KG) values in lake sediments ranged from 0.73 ϕ to 1.3ϕ, the Hazratbal and Gagribal basin sediments exhibit platykurtic nature where as the inflow channel Boddal and Nagin basin sediments showed leptokurtic nature which indicates the high silt deposition by the inflow channel.

The seasonal variation of major elements is very interesting as they show heterogeneous and anisotropic distributional pattern. Si and Al being high in summer (120094 μg/g and 50739 μg/g) and low in winter (94656 μg/g and 46531μg/g) reflecting that these elements are mainly derived from weathering of rocks from denuded catchment area, due to high inflow of water in summer. Ca and Mg being high in winter (15923 μg/g and 11029 μg/g) and low in summer (9293 μg/g and 6206 μg/g) respectively, such a trend may be due to their high mobility, dilution and intake by plants. Higher concentration of phosphorus in summer (612 μg/g) again depicts high anthropogenic activities, like use of fertilizers and waste material influx and heavy tourist pressure during summer. K being high in autumn (4297 μg/g) and low in spring (2451 μg/g). The autumnal increase is attributed to the fact that K is immobile and is adsorbed by the clay particles, as the clay proportion is more in autumn due to the diminishing of hydraulic flow that causes the settlement of fine particles.

Relative concentration of the heavy metals shows that Zn(220 μg/g) is dominant heavy metal followed by Cu (96 μg/g), Pb (21 μg/g) Co (19 μg/g) and Ni (17 μg/g). The higher values recorded at different sites are close to sewer drains, house boats, restaurants, etc, reflecting their source of anthropogenic origin.

The hydrochemistry of Dal Lake reveals that the surface water temperature shows slight spatial variation being comparatively higher at Gagribal basin (27.8^{0}C) and lower at Hazratbal basin (27.0^{0}C) near inflow channel. Increase in water temperature at Gagribal basin may be due to the influx of sewage waters from domestic sources and the lower temperature at Hazratbal basin near inflow channel may be due to continuous inflow of glacial melt waters. Like other fresh water lakes of Kashmir Valley, Dal Lake is alkaline in nature. Higher pH values recorded at Hazratbal (8.8) and Boddal (8.9) basins may be due to dissolution of carbonate rocks in the catchment area and the lesser pH values recorded at Gagribal (7.4) and Nagin (8.0) may be due to the input of sewage waters which are mostly acidic in nature. Spatial investigation of total dissolved solids and electric conductivity shows higher values (269 mg/l) and 420μs/cm at Gagribal and lower values (200mg/l and 312μs/cm at Hazratbal basin respectively, which point out the possibility of maximum water contamination due to domestic sewage waste solids and fertilizers used, rather than because of chemical weathering of drainage basin as maximum sediment load is shed down in Hazratbal basin than in Gagribal basin. Temporal variations shows higher concentration of total dissolved solids and electric conductivity during winter (246 mg/l and 384 μs/cm) and lower during summer (220 mg/l and 344 μs/cm). This high ionic strength in winter is probably due to less dilution during the periods of low water levels and due to decomposition of aquatic plants and animals which release abundant nutrients and the low ionic strength in summer is attributed to the high dilution and intake of ions by plants during this growing season. Dissolved oxygen shows lower concentration (5.3mg/l) in summer and higher concentration (10.5mg/l) in winter. This low concentration in summer is in consonance with the growth and abundance of aquatic plants during this season and the high concentration in winter may be as a result of low temperature and less biological activity. Relative variation of major ions in Dal Lake water depicts the predominance of Ca^{++} and HCO_3^- over the other ions and therefore the usual ionic progression is $HCO_3^- > Ca^{++} > Cl^- > Mg^{++} > Na^+ > K$. The higher concentration of Ca^{++} and HCO_3^- indicate that water has retained the chemical character of meteoric waters with some increasing concentration as Ca^{++} and HCO_3^- are higher in rain water /snow melt. The higher concentration of Ca^{++} (10.1mg/l to 45.7mg/l) and HCO_3^- (34mg/l to 201mg/l) indicates the intense chemical weathering of denuded catchment area, which mainly comprises carbonate and volcanic rocks. Lower Mg concentration in summer (5.4mg/l) is possibly due to its intake by the aquatic plants in the formation of chlorophyll-magnesium-porphyrin metal complex and in enzymatic transformation. Low Na^+ (1.5mg/l to 6.5mg/l) and K^+ (1.1mg/l to 3.8mg/l) concentration may be attributed to their low geochemical mobility. High Cl^- content is normally expected probably due to the dissolution of common salts and may be attributed to the presence of large amount of organic matter of both allochthonous and autochthonous origin. Higher SO_4^{--} (1.2mg/l to 6.7mg/l) concentration may be due to the association of gypsum/ anhydrite with the lacustrine deposits (Karewas) and some part of SO_4^{--} may come from agricultural sources. NO_3^- shows its highest concentration in Gagribal basin instead of Hazratbal basin. The higher values of NO_3^- at Gagribal (4.6mg/l to 13.9mg/l) and Nagin (2.5mg/l to 8.6mg/l) basins is a warning and an alarming signal of water pollution as the values approach up to 13.9 mg/l. As already mentioned the Gagribal basin is surrounded by dense populated area and is fed by number of waste water drains, besides the house-boats and restaurants where the tourist pressure during summer is very high. The increase of NO_3^- concentration during summer may also be due to use of fertilizers in parts of catchment area under agriculture and the floating gardens within the lake as soil amendments.

On the basis of piper trilinear diagram two chemical facies i.e Ca^{++} rich bicarbonate waters / Ca- HCO_3 type ($Ca \geq Mg$) and Hybrid waters / Ca-Mg-HCO_3 type ($Ca \approx Mg$) were identified.

TDS ranges from 200mg/l to 300 mg/l and weight ratio of Na / (Na + Ca) ranges from 0.1 to 0.3 , which shows that the Dal Lake waters are categorized as rock dominance suggesting that the major mechanism controlling the water chemistry of the Dal Lake is the chemical weathering of the rock forming minerals. To work out the possible liganding between cations and anions (Ca + Mg) versus total cations. (Na + K) versus total cations, (Ca + Mg) versus SO_4 + HCO_3 and (Ca + Mg) versus HCO_3, have been plotted and suggest a better correlation. The plots of Ca + Mg versus HCO_3 + SO_4 and (Ca + Mg) versus HCO_3 shows that most of the points approach the theoretical 1:1 trend, reflecting the derivation of cations from weathering of silicates and input of HCO_3 from weathering of carbonates.

Tempo-spatial variation of trace elements like Fe, Zn, Mn and Pb does not show marked differences, slight higher trace element contamination is noticed during summer near Gagribal basin sites close to house-boats sewage drains and restaurants reflecting the source of anthropogenic activities as a result of high tourist influx and agricultural practices during the summer season.

The results and observations reveals that the main factors responsible for the deterioration and eutrophication of the lake ecosystem are Increasing rate of sedimentation, Higher disposal of domestic waste and agricultural run-off, encroachments and reclamation of huge tracts in the form of floating gardens.

As a result of these anthropogenic perturbations the lake body has shrunk over half (11.45 Km^2) of the area. It was 22Km^2 at the turn of this century. The average depth has left only 2.5m, which was about 6m. It is clear that the condition of the lake has reached to a critical stage, from the hydrological and ecological point of view, when all conservative measures must be taken to save it from further deterioration. Some of the remedial measures may be taken include afforestation and soil conservation of catchment area, improvement of the settling basin on Talbal Nalla, control of encroachments including redevelopment of floating gardens, solid waste management, houseboat sanitation, marginal dredging, selective de-weeding, removal of Nishat bund for improving water circulation, improvement in regional sanitation and drainage system, extension of foreshore road around the lake and improvement of navigation routes, etc.

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"Dear is the memory of those who depart"

Dedicated

To the

Loving Memory

of

My Father

Late Muhammad Habibullah

THESIS

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Certificate

It is to certify that the thesis entitled ***"Environmental Geoindicators, Their Significance, Pollution Assessment, Determination of Source Areas and Remedial Measures in Dal Lake Catchment Areas, J&K "*** submitted by **Mr. Ab. Qoyeem Shah,** in fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Geology** of the Aligarh Muslim University, Aligarh, is a bonafide record of research work carried out under our joint supervision and guidance. The work embodied in this thesis has not been presented in part or full to any other university or institute for the award of any degree and is therefore forwarded for the submission to the award of Ph.D. degree of this University.

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CONTENTS

Acknowledgement

I want to express my sincere gratitude to the highly learned supervisor, **Prof. S.H.Israili** department of Geology, Aligarh Muslim University, Aligarh for his valuable guidance, keen interest and expert advice at every stage of this work.

I offer great regards to my co-supervisor, **Dr. A.K. Pandit**, Reader, University of Kashmir, Srinagar for his sympathetic attitude omniscient suggestions and generous assistance in planning this work.

I am extremely grateful to the chairman, Department of Geology, Aligarh Muslim University, Aligarh and Director, Department of Environmental Sciences, University of Kashmir for providing laboratory facilities to carry out practical work.

I specially thank to **Prof. M.I.Bhat**, Department of Geology and Geophysics, University of Kashmir, **Prof. A.R. Kaboo**, S.P. Collage Sirnagar and **Mr. Ab. Hamid Zargar**, lecturer SKUAST, Srinagar for providing valuable literature and encouragement during the research work.

My thanks are due to **Dr. Shakeel Ahmad**, **Mr. Ali Mohamad** and **Mr. Ramesh Chandra Panth** for their technical assistance in the analytic work.

I shall never forget the personal pains taking of Dr. S.Jeelani and Mr. Mushtaq Ahmad in compiling and executing this work.

I express heartiest wishes to all my friends particularly Fayaz Sogami, Javid, Hamid, Asif, Shahab, faisal and Fayaz for their cooperation and timely help in the completion of this work. My thanks are due to Staff of Anglo Computer for typing this manuscript.

The acknowledgement would remain incomplete without expressing special regards to my family members for their support, encouragement and good wishes throughout this work. I bow in reverence to my parents whose love and affection in addition to financial support boosted my morale and made me enthusiastic to achieve academic heights with determination and patience.

(Ab. Qoyeem Shah)

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

Chapter-1
Introduction

INTRODUCTION

In a geological prospective lakes are regarded as temporary waterbodies on the land surface formed generally by some drastic geological events, volcanism, earthquake or glaciation and constitute only about 1% of the earths continental surface and contain < 0.02% of total hydrospheric water. In spite of this meagre figure, lakes are of great geological, geochemical and geo-limnological significance and serve as natural laboratories where physio-chemical and biological aspects of not only lacustrine environment are refined but recently, investigations in deep, stratified lakes have led to a better understanding of oceanic anoxic events as most of the processes operating in lakes are similar to those in oceans. The global distribution of lakes does not have any definite spatial distributional pattern but are scattered all over the world on high mountains, plateaus and low lying plains. Though these small objects are present on the face of the earth in all continents from equator to the poles but are more abundantly found in the high latitude areas of North and South America and West Europe. Some lakes are found on high altitudes, more than 18000feet AMSL (Tso-Sekuru Lake) in Tibetan Plateau and some are below sea level (Dead Sea) situated 1300 feet below sea level. Practically all lakes have their own life history and possess different characteristic features regarding the depth and aerial extension.

Lake sediments contain valuable evaporatic minerals and oil shales and they provide sites for uranium fixation. They also serve as source rocks for hydrocarbons and some major iron ore bodies, particularly the banded iron formation may occur in lacustrine rocks. Lacustrine sediments also play an important role in order to elucidate the many processes occurring within the total lake system, including its surrounding surface and groundwater drainage basins. Of course, lake bottoms have long been recognized as the depositional site of both mineral and organic metal that is transported to the lake from the drainage basin, as well as matter which forms and settles from within the waterbody.

In more recent years, however, there has been a growing awareness of the role, the sediments play in the dynamics of lake system. Recycling of mineralized organic matter, especially the nutrients in sediments by organic decay and pore fluid transfer processes are now recognized as essential components of models that attempt to describe the nutrient dynamics of the lake systems. In addition the active role lake systems play in regulating cycles of trace metals, radionuclides and synthetic organic chemicals (pesticides, soaps, synthetic effluents, etc.) is gaining increasing attention, particularly in culturally developed areas of the world. Similarly, the nature of lake water also gives definite status to a lake body regarding its biological productivity and provide an important information to understand the various physico-chemical and biological activities carried out in the whole lake ecosystem. Salinity being the significant characteristic feature of lakes as salts of varied composition are taken out from the rocks and are brought to the lakes through surface runoff, rivers, seepage of ground water, rain and melt water through melting of glaciers, ice caps, etc. Salt concentration thus increases and gradually accumulates in the lakes due to which in due course of time a freshwater lake may become saline and in some freshwater lakes salinity increases to such an extent that the whole biological productivity in such a environment is minimized to its least.

A major emphasis to the study of lakes and their deposits have undoubtedly been their potential ecological and economical importance as the lakes, being sensitive to climate and geomorphological conditions of the catchment area. Thus both the relief of the drainage area and the lake basin remains always under constant alteration by exogenic forces like weathering, erosion, transport and deposition. As a net result the lake sediments, are thus the basic geo-indicators of paleoclimate and provide an elusive but rich information about the whole components of entire drainage basin and thus can be regarded as a bank of environmental information or as an environmental "Tachnometer" (Hakanson and Jansson, 1983).

1.1 KASHMIR VALLEY AND ITS LAKES

The high altitude valley of Kashmir is a lacustrine basin of Pleistocene origin existing between the Pir-Panjal range in the southwest and the Great Himalayas (Himadri) in the Northeast. The basin of intermontane depression is the net result of tectonic activity bounded either side by regional faults trending in NW-SE direction. The basin floor stands 1585m AMSL, being 135 km long with a maximum width being 40 km, and occupies Northern most geographical position in India.

The Kashmir Valley lies in NW Himalaya. constituting the most important segment of the Himalayan mountain range, had gone through all episodes of the Himalayan Orogeny, besides witnessing various geological changes and the large-scale glaciation in Pleistocene periods. The presence of lacustrine Karewa deposits within the Valley reveals that the whole Valley was once a glacial lake, which found its outlet due to over spilling at Baramula few million years ago and drained.

Kashmir valley has innumerable freshwater bodies, (lakes, wetlands, ponds, rivers and streams) which are not only important for ecological, socio-economical and cultural heritage of the state but also serve as primary resource for the upliftment of local economy. Besides, 80% population of Valley is entirely dependent on these waterbodies used for drinking, irrigation and domestic purposes while most of the water bodies have been maintained and decorated for tourist purposes and are the best health resorts of Kashmir Valley.

The freshwater natural lakes of Kashmir Himalaya are mainly of three different types with respect to their origin, altitude and nature of biota they contain (Table 1.1).

(i) The glacial upper mountain oligotrophic lakes (Alipather. Gangabal, Kouncernag, Krishansar, Tarsar. Marsar. Sheshnag. Vishnusar, etc) situated on between an altitude of 3000-4000m AMSL.

Table 1.1: Description of lakes in Kashmir Himalaya (c.f. Pandit, 1994).

Lake	Attitude (m)	Origin	Area (km)^2	Max. depth	Trophic status	Location
I. Upper mountain lakes						
1. Alipathar	3,200	Glacial	0.08	6.5	Ultra-oligotrophic	In Pir Panjal Range of Kashmir Himalaya in the east of Kashmir
2. Tarsar	>3,500	Glacial	-	-	Ultra-oligotrophic	Towards northeast of Kashmir
3. Marsar	>3,500	Glacial	-	-	Ultra-oligotrophic	Towards northeast of Kashmir
4. Sheshnag	3,572	Glacial	0.51	13.0	Ultra-oligotrophic	Towards northeast of Kashmir
5. Toulian	>3,000	Glacial	-	-	Ultra-oligotrophic	Towards northeast of Kashmir
6. Gangabal	3,568	Glacial	1.57	83.5	Ultra-oligotrophic	Towards northeast of Kashmir
7. Kounsemag	3,510	Glacial	1.37	81.0	Ultra-oligotrophic	Towards northeast of Kashmir
8. Vishansar	>3,500	Glacial	-	-	Oilgotrophic	Towards northeast of Kashmir
9. Kishansar	3,500	Glacial	-	-	Oilgotrophic	Towards northeast of Kashmir
10. Nundkol	3,565	Glacial	0.11	8.0	Oilgotrophic	Towards northeast of Kashmir
II. Pine Forest Lake						
11. Nilnag	2,180	Tectonic	0.063	6.5	Mesotrophic	Towards south of Kashmir at the foothills of Pir Panjal range/semi-on a range type.
III. Valley lakes						
12. Dal	1,584	Fluviatile	11.50	6.0	Moderate eutrophic	Urban lake in the north east of Sninagar city/Open drainage type.
13. Anchar	1,584	Fluviatile	6.60	2.75	Moderate high eutrophic	Urban lake in the north west of Kashmir/Open drainage type
14.Wular	1,580	Fluviatile	189.00	5.8	Momoderate eutrophic	Rural lake towards north west of Kashmir (near Bandipora and Sopore)/ open drainage type.
15. Mansbal	1,583	Fluviatile	2.81	12.0	Mesotrophic low eutrophic	Rural lake towards north west of Kashmir (near Bandipora and Sopore)/ open drainage type
16. Naranbagh	1,587	Fluviatile	0.24	5.42	Mesotrophic	Rural lake towards north west of Kashmir (near Bandipora and Sopore)/ open drainage type.
17. Khanpur	1,584	Fluviatile	1.35	4.5	Moderate eutrophic	Rural lake in the north west of Srinagar and (Ganderbal tehsil) semi-drainage type
18. Trigam	1,510	Fluviatile	1.40	2.3	Highly eutrophic (polluted)	Rural lake in the northwest of Srinagar and (Gandarbal tehsil, Non-drainage type.
19. Tilwan	1,565	Fluviatile	4.35	2.2	Highly eutrophic (polluted)	Rural lake in the northwest of Sringar/ Non-drainage type
20. Pashakuri	1,580	Fluviatile	0.10	1.5	Highly eutrophic (polluted)	Rural lake towards south of Srinagar (near Pampore) Non-drainage type.

(ii) The lakes of tectonic origin being mesotrophic (Pine forest lake-Nilnag)) present in the lower fringes of Pir Panjal range at an altitude of 2000-2500m AMSL and

(iii) The eutrophic valley lakes of fluviatile origin (Dal, Anchar, Mansbal, Wular, Trigam, Tilwan, etc.) are situated in the low lying areas at an altitude of 1560-1600 m AMSL.

Mostly, Valley lakes occur all along the floodplains of the river Jhelum, the only recipient of the whole drainage of the Valley through the alluvium of its own deposition and covers a distance of 144 km from Verinag spring to Baramula. Since most of valley lakes particularly Dal Lake, are fed by melt waters from glacial lakes of the Himalaya such as Tarsar, Marsar glacial lakes of Dachigam catchment area, so it is here important to give a brief idea about the glacial lakes, glacial melt water and sediment transport and hydrochemistry of melt waters present in the Himalaya.

1.2 GLACIAL LAKES

The Great Himalaya which bounds the Kashmir Valley towards NE provides an appropriate condition for a stable existence of cryosphere covered by snow and glaciers at an altitude of about >4000 m above mean sea level. Some of these glaciers have glacial lakes, the formation of these lakes seems to have accelerated in recent times (Yamada 1998) and is believed to be visual evidence of the global warming (Hasnain, 1999). All the glaciers in the Himalaya and Karakoram mountains are in a state of retreat since the middle of the 19th century. Two types of glacial lakes have been found in the Himalaya: moraine dammed lakes and ice-dammed lakes (Hasnain, 1999). Most of the lakes are moraine dammed in origin and ice dammed lakes are rare. Himalayan glaciers produce very large amount of debris as compared to other glaciers in the world.X

X Hasnain, S. I. et. al (1989).

1.3 SEDIMENT TRANSPORT IN GLACIAL MELT WATER

Glacier streams transport great load of sediment (silt, sand, gravel and boulder) that result from erosion. It is mainly carried in suspension and some is moved along the bed. It is assumed that the suspended load accounts for about 40 to 50% of the total load carried by the glacier stream at the ice front. Results of the sediment study will not only give valuable information about glacier erosion under various conditions but also indicate the possible rates of sedimentation that can be expected in reservoirs and lakes along rivers and streams from galcierised areas.

Besides the sediment input, some debris is also added to the streams like Talbal nala from fluvial erosion, which is ultimately brought to the basin like Dal Lake. In other words the sediments are brought from whole catchment area and represent the area through which the melt water pass i.e. the sediment transport is derived either directly from glacial erosion (glacial processors) or reworked along the river system (non-glacial processors). Small (1987) reported that approximately 40-50% of sediment transported by the glacier is deposited in lateral

X The Reference pointed out have been cited under the heading of Additional References in the thesis.

moraines and at the glacier snout. Maizels (1978) found that pro-glacial zones also act as an important sink and 16% of fluvioglacial debris is deposited in the valley sides. However, in basins far away from pro-glacial zone a considerable amount of sediment is stored within the fluvial system.

1.4 GLACIAL HYDROCHEMISTRY

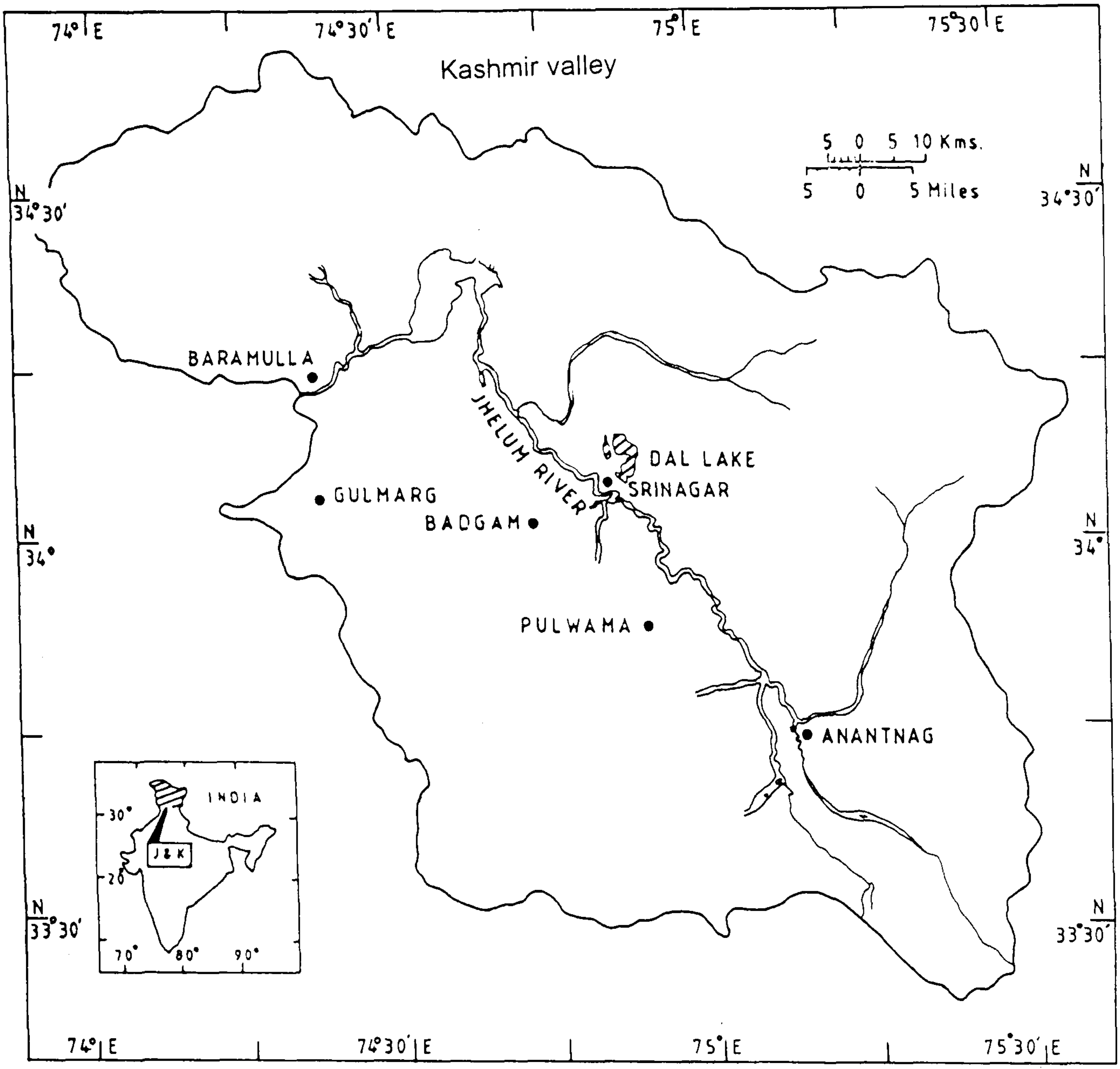
The glacial melt water compositions are similar to those for other low solute content waters and have a low buffer capacity, which allows pH to vary widely in response to the local chemical environment. The hydrochemistry of glacial melt waters gives a clear picture of the intensity of geochemical weathering of the drainage basin and percentage of solute acquisition (Hasnain *et al.*, 1989). High rates of chemical weathering are as a result of rapid dissolution of the minerals, which come in contact with the melt water flowing in streams and continuously add the chemical constituents to water. The melt water while flowing through different rock types carry the chemical signature of the rock types, as the water acquires the chemical composition due to the dissolution of minerals and thus one can infer the geology of the drainage basin on the basis of chemical composition of water.

1.5 LOCATION AND DESCRIPTION OF THE STUDY AREA

Dal lake, the urban valley lake of fluviatile origin, is situated at an altitude of 1583m AMSL between 34^0 6'-34^0 10'N latitude and 74^0 50' -74^0 54' E longitude in the heart of the Kashmir Valley on the northeast of the state summar capital Srinagar at the foot of Zabarwan mountains (Fig.1.1). Though a small shallow lake, it has been the center of Kashmiri civilization and plays an important role in the economy of the Valley through its tourist attraction and its utilization as source of food and water. The world famous *nadroo* (a vegetable) grows in the Dal Lake. The total water surface area of the lake is 11.45 km^2 of which 4.1 km^2 is under floating gardens, 1.51 km^2 and 2.25 km^2 are land and marsh respectively whereas the total volume estimated is 9.83×10^6 m^3 and the ratio between the mean and maximum depth (m) ranges between 0.20 and 0.25, indicating the gentle slope of the lake bed.

This open drainage eutrophic lake is multibasined with the Hazratbal, Boddal, Gagribal and Nagin as its four basins, which differ markedly in their area, volume, depth and shoreline development indices etc. The lake area extending from Kotarkhana to Nishat bund constitutes the largest basin of the lake (Boddal basin) occupying the surface area of 5.7km^2 with small island Rupa lank in its center. Among the lake basins, Nagin is the smallest and deepest basin with surface area of 0.89 km^2 and maximum depth of 5.7m respectively, while Gagribal is shallower basin being 2.5m deep extending from Kotarkhana to Nehru park having the total surface area of 1.30 km^2.The fourth basin of the lake is Hazratbal basin in the middle of which lies the famous island, Sona lank, with lofty chinar trees and the Holly Hazratbal shrine on its eastern bank, constituting about 33.50% of the total surface area. Hazratbal basin is

Fig. 1.1 Location map of the study area



3.2m long, 1.6m wide and 3.5m deep bounded by the renowned Mughal gardens (Nishat, Shalimar and Cheshmashahi) along the western shore line. Besides the numerous springs from lake bed, the lake is fed by a myriad of small streams i.e Peshpaw nala, Shalimar nala, Mearkhshah nala and Harshii kul etc. from a catchement area of about 317 km^2 around its shore line and by one large perennial Inflow channel Telbal nala which drains the largest sub-catchment area of 145 km^2 into the lake contributing about 80%of the total annual inflow to the lake (Zutshi, 1982). In addition numerous sewage drains from human settlements also flow into the lake. The outflow from the lake is through weir and lock system at Dalgate into an arm of river Jhelum near Chinar bagh and via Nagin basin through a canal Amir Khan nala which connects it with Anchar lake.

As a moderately large and cold water lake effected by a variety of human influences, is not only shrinking in its surface area but its waters are also becoming polluted, posing health hazards to many people. The pronounced shoreline development, changing littoral extent, complicated hydrology and variable water chemistry are the factors that enhance the value of Dal Lake for investigations. In order to asses the pollution sources, types and sites, an attempt is made here by the analysis of texture end geochemistry of lake sediments and the physico-chemical characteristics of lake water. Besides highlighting a number of pollution hazards that the lake is facing, the potential remedial measures are proposed for the Dal Lake restoration.

1.6 REVIEW OF LITERATURE

Previous work related to geology of the area is carried out mainly by the Geological Survey of India (GSI). The observations on geology, paleontology and petrology have been recorded by various workers since long.

However, the first authentic geological account is given by Godwin Austen, an army surveyor (1866), who introduced Paleozoic stratigraphy of Kashmir Valley.

Drew (1875), the then state geologist of the Maharaja of Kashmir has given a fairly detailed account of Karewa deposits. He made a clear distinction between the younger alluvium and the older Karewas. Lydekker (1883), the first officer of Geological survey of India, produced first geological map and made the first systematic study of the stratigraphy. Middlemiss (1909, 1910, and 1911) gave a detailed account of stratigraphy of southeastern part of the Valley. His work is considered as the base work which is still followed with some modifications from time to time. deTerra and Patterson (1939), as member of Yale North India expedition, carried out by far the most comprehensive field work on Karewas. They inferred that Kashmir region has underground freezing climatic conditions during

γ The Reference pointed out have been cited under the heading of Additional References in the thesis.

Pleistocene, the freezing have taken place in four successive cycles. Wadia (1934) mapped the northwestern part of the Kashmir Valley including the Pir Panjal and established the stratigraphy of the area. The lower Paleozoic sequence of the NW Kashmir was also studied by Shah (1968, 1972), Raina and Razdan (1975), and Shah (1980).

Kalhana did not mention about Dal Lake in Rajtarangni, the ancient history of Kashmir written by him in 12th century. However, he mentioned about two Islands of Dal Lake. Zainul-Abidin (1420-1470 A.D) used the lake for recreation and beautified its surroundings. Drew (1875) is the first who measured the area of Dal Lake.

Hutchinson (1932) was the first who carried out the limnological studies of Kashmir Lakes. Wadia (1934) and de Terra and Patterson (1939) showed that the Dal Lake is derived from enlarged oxbows rather than the relics of the ancient lake. de Terra and Patterson (1937) were first who have presented data on the distribution of detritus and mineral grains in different basins of Dal Lake. X Zutshi *et al.* (1968) studied the sediment chemistry of Hazratbal basin of Dal Lake.

X Enex (1978) measured total surface area and gave a comprehensive report on Dal Lake pollution. Vass and Zutshi (1979) discussed the water level fluctuation of Dal Lake. Further, X Zutshi *et al.*

X The References pointed out have been cited under the heading of Additional References in the thesis.

(1980) studied the thermal behavior of Hazratbal basin of Dal Lake. Agarwal (1981) studied the surface sediments of various basins of Dal Lake. Zutshi and Vass (1982) deal with limnological studies and discussed the chemical and biological features of Dal Lake.

Kango (1983) discusses the phosphorus dynamics of Hazratbal basin. Trisal and Kaul (1983) studied the mud-water interaction in Dal Lake. Kango (1984) studied the aquatic sediments of some Himalayan lakes including Dal Lake. Kango and Zutshi (1986) discussed the distribution and balance of ortho particulate and total phosphorus in northern basin of Dal Lake. Further, Kango *et al.* (1986) discussed the interaction of humic acid with heavy metals like Cu, Zn, Fe, Mn. Palria (1987) studied the water quality mapping in Dal and Wular Lakes by using aerial photographs and landsat imageries. Kango(1987) and Kango *et al.* (1987) studied the distribution of Fe, Mn and Zn in Himalayan Lake sediments. Zutshi (1987) discussed the impact of human activities on Dal Lake environmental evolution. Shah *et al* (1988) studied the metallic elements in surface sediments of Dal Lake. Sarwar (1989) worked out liminological features of Kashmir Lakes. Zutshi and Ticku (1990) discussed the impact of mechanical deweeding on Dal Lake ecosystem. Pandit (1992) studied the impact of macrophytes on Dal Lake ecosystem. Pandit (1992) described macrophytes as an important component of Dal Lake ecosystem in Kashmir. Pandit (1993) reviewed the entire work on ecology of Dal Lake ecosystem in Kashmir Himalaya and suggested management tools to save dying Lake. Pandit (1996) highlighted various

The References pointed out have been cited under the heading of Additional References in the thesis.

ecological aspects of Kashmir Lakes and described certain factors, which lead to the degradation of Kashmir Lakes. Recently, the entire work on freshwater ecosystem of Kashmir Himalaya, comprising wetlands and lakes in general and Dal Lake in particular, was compiled in the form of a book entitle "Freshwater Ecosystem of the Himalaya" being authored by Pandit (1999) and quite recently[X] Pandit *et al* (2002) studied the physicochemical features of freshwaters of Kashmir Himalaya including Dal Lake. The trophic evolution and conservation of Kashmir Himalaya lakes including Dal Lake were highlighted in more recent works of Pandit (2002).

1.7 SCOPE OF THE WORK

The present work is significant due to following reasons:

- It gives an idea about the sediment transport, their distribution and texture, besides the behavior of chemical constituents within the sediments
- It heralds the initiation of attempts towards understanding the hydrogeochemistry of the Dal Lake.
- It gives quality assessment of Dal Lake water as this is the main source of water for Srinagar city for drinking, domestic and other purposes and gives information valuable from the point of view of public health.
- It provides information related to the type and sources of pollution.
- Quality characterization, causes, impact and remedial measures

X The Reference pointed out have been cited under the heading of Additional References in the thesis.

Chapter-2
Climate, Physiography and Drainage

CLIMATE, PHYSIOGRAPHY AND DRAINAGE

In general, the genesis of Kashmir weather is intrinsically linked with the mechanism of weather in the Indian Subcontinent and is influenced greatly by the Himalaya, a vast barrier nearly 3,200 km long, separating high dry Tibetan plateau from the low humid subtropical lands of Ganges and Brahamputra. Thus, the diverse physical features and location between the weak monsoon zone of Punjab and cold dry belt of Ladakh and Tibet result in Kashmir having a typical type of climate. The present physiography of the Kashmir region is directly controlled by the formation of the Himalayas. During the Himalayan orogeny, excessive compressive forces resulted in crustal shortening due to which folds, thrusts and nappes were developed. The Kashmir region consists of huge mountain masses interspersed by longitudinal valleys. The mountain ranges represent the anticlines and the longitudinal valleys the synclines of the main Himalayan folds.

2.1 CLIMATE

The general climatic conditions of Kashmir Valley as such are transitional resembling sub-Mediterranean type and characterized by a rainfall occurring throughout the year except 2 to 3 dry periods in summer and autumn. The snowfall data shows that January has the highest frequency of days with snow followed by the February and December.

Depending upon the duration and magnitude of precipitation and temperature the year is divided into following four seasons:

(i) Spring (March to May).

(ii) Summer (June to August).

(iii) Autumn (September to November).

(iv) Winter (December to February)

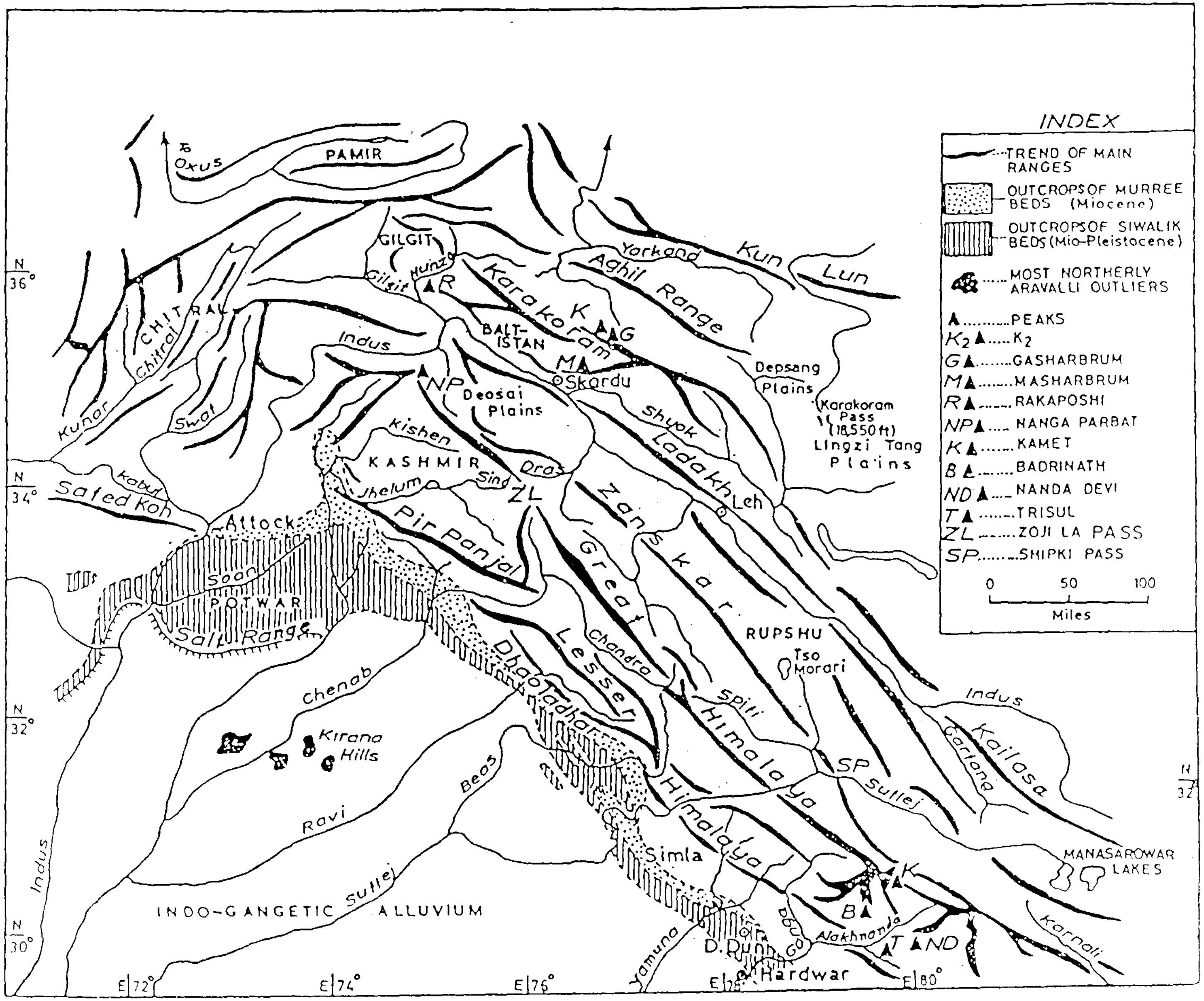
The spring season with bright days and cool nights observed frequent rains and the maximum number of rainy day (11 days) occurred in the month of April 2001. Where as in summer season day temperature remains remarkably high and constant, indicating July as the hottest month of the year with a maximum temperature record of 34.7 ^{0}C. Dryness being the distinctive feature of autumn season in the Valley, the monthly precipitation fluctuates from autumn low to summer high with maximum of 69.7mm occurring in January and the minimum (0 mm) during October, indicating October as the driest month of the year. Not much variation was measured in the atmospheric pressure and the values fluctuated from 834.3 hpa - 847.7 hpa at 08.30hr and 831.7 - 845.2 hpa at 17.30hr.The monthly maximum mean (88%) relative humidity at 08.30hr occurred in January as against minimum (41%) at 17.30hr in April and May respectively.

2.2 PHYSIOGRAPHY

Predominance of majestic mountain ranges with snowclad peaks. large longitudinal valleys of subsequent streams occupying deep gorges, transverse gorges cut across the ranges by antecedent streams, strategic mountain passes facilitating transportation, dearth of extensive alluvial plains, preponderance of glaciers and patches of snow fields, plateau like features developed in thick accumulations of the Pleistocene glacial morains (Karewas), the Kashmir valley occupying a somewhat flexure basin but quite unique in its natural beauty and numerous glacial lakes are some of the characteristic features of Kashmir valley (Spate and Learmonth, 1967). Broadly speaking, the Kashmir region consists of two huge mountain masses– the Karakoram in the far North, the Himalayas/Zanskar to the south; and on the southern flanks of the main Himalayas, the famous Valley, the valley of Kashmir walled in by the Pir Panjal towards southwest. We can say that the valley of Kashmir lies between the Pir Panjal and the main Himalayas. The trend of Kashmir Valley and its surrounding mountains are shown in Fig. 2.1. and the cross section across the Kashmir Himalayas is shown in Fig. 2.2. The NW-SE tectonic basin is 135km in length with a maximum width of 40 km with a floor which is Jhelum floodplain is only 1585 m above sea level. The faceted spurs in the gentle slopes of Pir Panjal give a clear indication of faulting. These spurs are marked by the Pleistocene deposits. The river Jhelum flows close to the northern side of the valley.

The Pir Panjal is in a bifurcation from the main Himalaya farther east. Wadia (1934) considers the thrusting as the front of great Kashmir

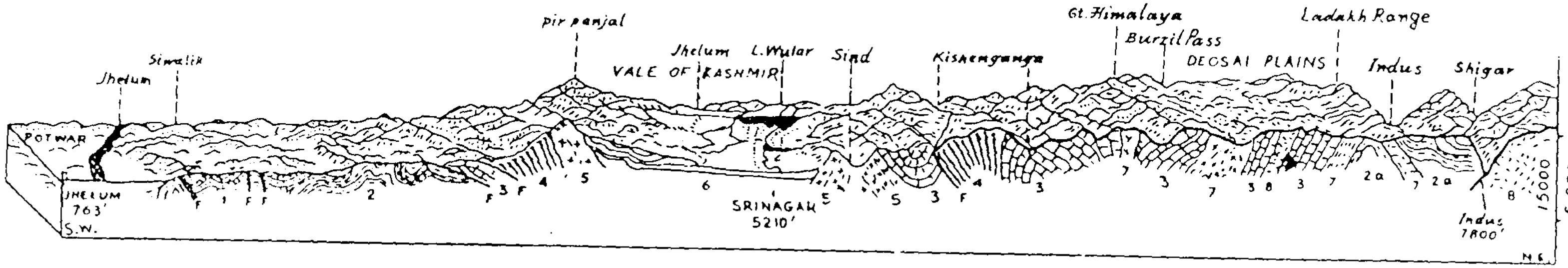
Fig. 2.1 Map showing trends of the principal mountain range in the NW Himalayan complex.



SOURCE: O.H.K.Spate, INDIA AND PAKISTAN 1967 nappe. The Permo-carboniferous limestones, metamorphics and intrusives form a broad swelling platform at about 3,960m, on which a serrated residual crest, the highest reaching 4,725 m and the Passes lie around 3,500 m. Most of the thirty odd small glaciers are on the northern slope in contrast to the Himalayas farther east. This is because the Pir Panjal snow comes mostly in winter from west and northwest and the southern side is more exposed to warm air currents from the plains.

The Great Himalayan ranges include the Zanskar range and the Indus is entrenched between them. The Great Himalayas are made up of the roots of the Kashmir nappe, the principal geoanticline within the main Himalayan geosyncline, consisting of the Archean and Pre-Cambrian sedimentary rocks together with large bodies of intrusive granites and basic masses. At its western end near Indus bend, the mighty Nanga Parbat attains an elevation of 8,126 m in its highest peaks with a large number of peaks that exceed 4,500 m in elevation. On the NW slopes of Nanga Parbat a large number of glaciers with large dimensions are found. The important passes in the great Himalayan ranges are below 5716 m. To the south lies the eastern continuation of the Pir Panjal (4,572–5,486 m) and farther South are the Dhaoladhar ranges (3,048–4,572 m). The high Zanskar peaks are seated upon a broad plateau like range, much dissected, at about 5,945 m. The Great Himalayas remain almost snow bound through out the year.

Fig. 2.2 Map showing block section of Kashmir Himalayas



BLOCK SECTION OF KASHMIR HIMALAYAS (POTWAR TO LADAKH). LINE OF SECTION ON BEARING 38° FOR 690KM. FROM JHELUM TOWN TO INDUS BELOW SHYOK CONFLUENCE. GEOLOGY (BASED ON de TERRA) DIAGRAMMATIC : 1, SIWALIKS; 2, MURREE; 2a, FLYSCH; 3, PERMO-CARBO. (THRUST ON TO 2), AND 'TETHYS' FORMATION (U.PERMIAN CRETACEOUS) IN NORTHEAST; 4, OLDER PALAEOZOIC; 5, YOUNGER PALAEOZOIC IGNEOUS; 6, KAREWAS BEDS; 7, CRET.– EOCENE ERUPTIVES; 8, GRANITES. F, MAJOR FAULTS AND THRUSTS.

SOURCE : Spate, O.H.K. AND Learmonth, A.T.A., INDIA AND PAKISTAN, 1967.

The origin of Valley itself is obscure; Wadia (1934) speaks of it as 'an exaggerated instance of a dun' or longitudinal valley. He shows it as occupying a syncline on the back of the great Kashmir nappe; While de Terra (1939) holds that it is a recently formed depression, an intermontane basin pointing to marked evidence of faulting on the Himalayan flank. The floor of the Vale is formed mainly by the terraces of the Karewa beds which are the fluvio-glacial deposits of Pleistocene age. These deposits consist of clay, sand and silt of lacustrine origin in which bands of marl and loessic silt with lenticles of conglomerate from old deltaic fans bears witness of many fluctuation of levels. The sequence of events as suggested by de Terra (1939) is as under:

(i) Capture by the Jhelum of an original subsequent stream flowing to the SE, probably along the coarse of Chenab,

(ii) Blocking of this exit by the Pir Panjal uplift,

(iii) Filling of lake and over spilling,

(vi) Alternate draining and deepening of the lake in response to glacial changes and changes in the ratio of uplift and erosion at the spill,

(iv) Continued uplift accompanied by cutting down of Jhelum and complete draining of the lake.

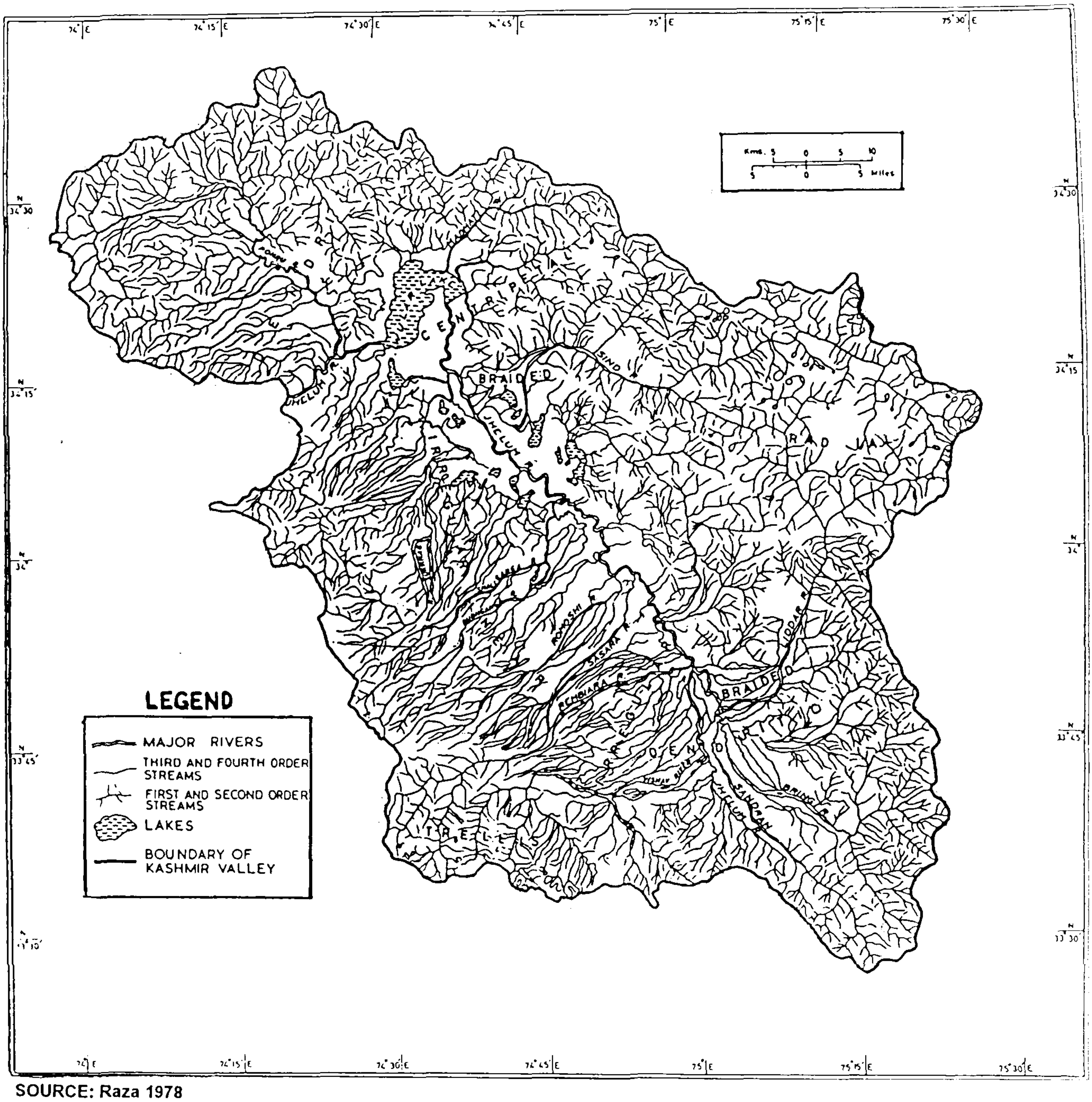
The various existing lakes are not the relics of the ancient lake rather enlarged old oxbows of the Jhelum. At places the Karewas have been eaten by the Jhelum into great buffs and the terrace lying at 137 m above the river. On the southern side of the Kashmir Valley the Karewa beds extend from 66,45 m to 2,740 m and are quite steeply tilted. These deposits were folded and at place faulted by the Pir Panjal uplift. The Karewas are usually permeable with poor soil, though pressure of population enforces their cultivation.

Geomorphologically the area is represented by a vast valley, high structural hills, small mounds of Karewa in the valley portion and colluvial fans below the hill slopes (Singh and Sharma, 1999).

2.3 DRAINAGE SYSTEMS

The drainage map of Kashmir Valley is shown in Fig. 2.3. The drainage system of Kashmir region possesses some classical examples of antecedent drainage. The Indus takes its origin from Tibetean plateau and crosses the Great Himalayas through a deep cut gorge. The Jhelum is the only master stream draining whole of the Kashmir Valley, is known to the Kashmiris as the *Veth*. When it leaves at Baramula it is called the *Kashur Darya* and after joining the Kishenganga is spoken of as the Jhelum river . Now, the whole river from Verinag onwards is known as the Jhelum river. From Verinag spring to Kichhama, the point below Baramula where the Jhelum leaves the Valley, it covers a distance of 196km. From Khanabal (Anantnag) to the great Wular lake (Considered as the delta of the Jhelum in Kashmir) the fall of the river is 50m in the first 48km and 16m in the next 38km

Fig. 2.3 Drainage map of Kashmir valley



SOURCE: Raza 1978

(Lawrence, 1967). The fall is slight onwards. The river after joining the Wular lake near Sopore flows in a narrow gorge across the Pir Panjal at Baramula, where it turns towards the south along a bend. This bend is referred by Wadia as syntaxial bend (Wadia 1934). The river is at its peak during summer and lowest during winter. The river takes its origin from a number of streams coming down from the Great Himalayas and the Pir Panjal and numreous springs of Anantnag. The river arose from the great spring of deep blue water of about 16m feet deep from the surface, at Verinag which bubbles up underneath a steep scarp of rock clothed with pines. From south above Khanabal the mountain streams, the Sandrin, the Breng, the Arpat from Kotahar, the Kokernag and the Achabal springs join the river. The right hand tributaries include the Liddar or Lambodri, an important tributary which comes down from the everlasting snows from the Great Himalayas and from the glacial lake of Tarsar meets it just below Khanabal; Aripalnag and the drainage from the Wasturwan and the mountains above Tral which meet the main river further down; a small amount of overflow from irrigation channels fall into the river at Pampur; Dal Lake feeds the river at Srinagar; the Sind river, the main tributary joins it at Shadipora and the Pohru stream enter it at Dubgau. The Kishenganga is the tributary joining the Jhelum after it crosses the Valley.

The main left hand tributaries within the Valley are a number of minor streams, known as *Kuls* in Kashmiri, draining the Karewas. These tributaries include the Vishau, the Rembiara, the Ramshi and the Dudganga, which joins the main river at the lower end of the Srinagar city. The Suknag and the Ferozpora stream lose themselves in the large marshes under the banks of the Jhelum and the Ningil flows into the Wular lake.

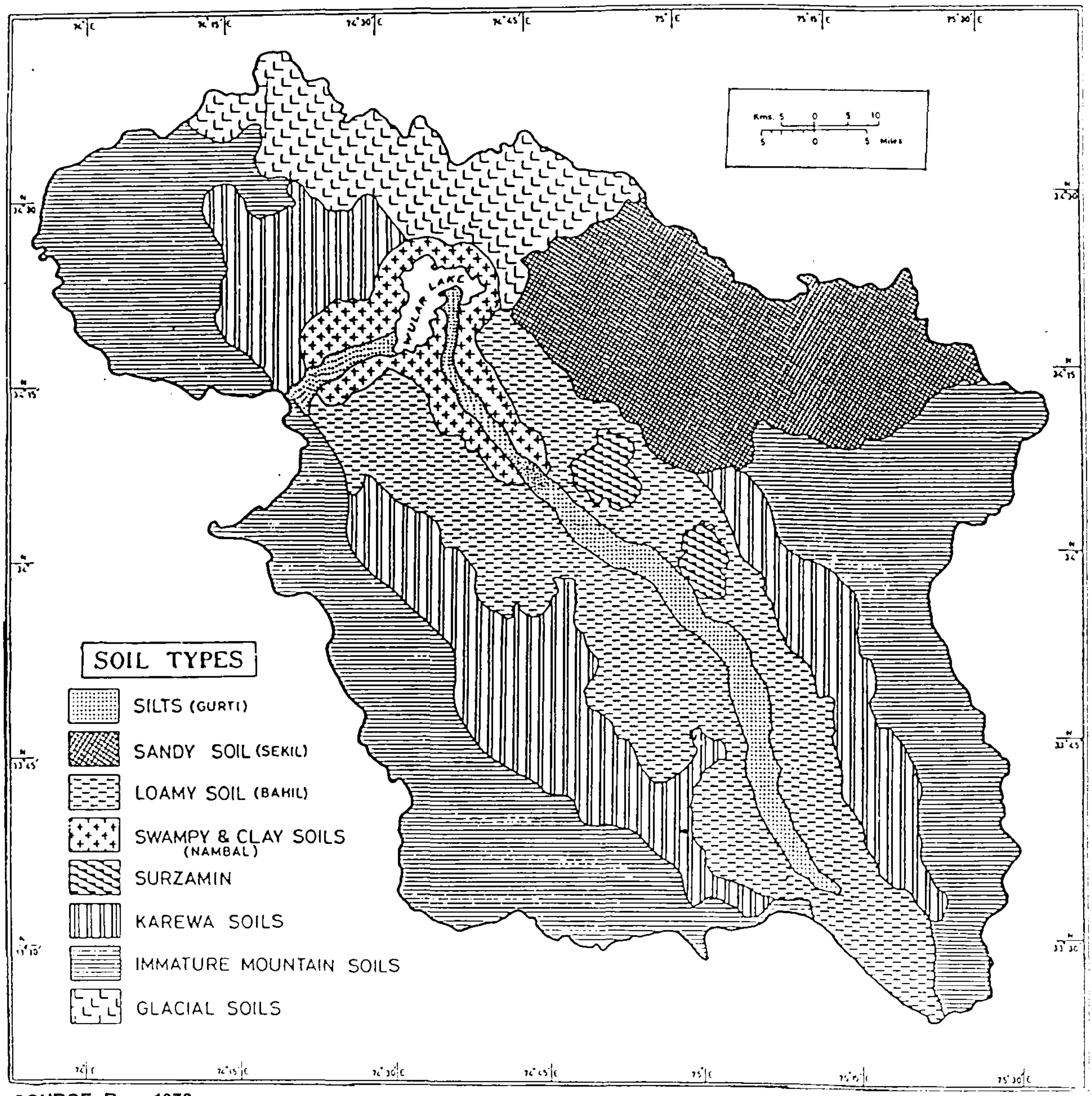
Drainage Pattern

The stream pattern of the Kashmir Valley is interesting. The northern wall is dissected by the Sind and other rivers which are antecedent to the immediately bordering hills, but beyond the ridge crowned by Harmukh, the north western end of the Valley shows a well adjusted synclinal pattern suggestive of an ancient neadwater portion of a master stream. On the Pir Panjal side the upper valleys are incised and dendritic, but further down, the rivers have developed a parallel coarse, consequent on the uplift of the Karewa beds and antecedent to the folds in them.

2.4 SOIL TYPES

The soils of the Kashmir Valley (Fig. 2.4) are of alluvial, lacustrine and glacial origin. However, their present day variation is mainly due to the climate (Raza,1978). There is an enormous thickness of soil in the bowl of Kashmir and in the adjoining terraces, which were formed during Pleistocene times. The soil is richest in the low-lying areas along the Jhelum, which is renewed and enriched by floods. The thickness and fertility of the soil, however, deteriorate with altitude. In the high

Fig. 2.4 Map showing soil types of Kashmir valley



SOURCE: Raza 1978

lands, the rocks are often exposed and no soil occurs there because of steep slope, low temperature and strong winds. The soils of Kashmir are classified with reference of broad physiographic divisions and are as under:

(1) Valley soils

(2) High land soils and

(3) Karewa soils

The soils of the Valley basin and the side valleys of the Jhelum are high in nitrogen content, organic matter and other plant nutrients which raises its fertility. They have high content of P_2O_5 and K_2O and are fairly rich in Ca^{++} and Mg^{++}. pH of the soil ranges from 6.5 to 7.2 .

The highland soils are deficient in bases. Important differences in soil types within the highlands are observed which depend mainly on site, nature of slope, and altitude. The valleys and patches of flat land even at higher elevation may have a deep soil layer with high humus content. The immature soils are found on the steep mountains. The soils are mostly silty clay loams. They are having high nutrient status and low content of calcium carbonate. These soils show a low pH value also. The Karewa soils are poorer and are mostly composed of silts and are by and large devoid of a vegetal cover and the soil lacks organic matter. The Karewa gurty types are distinguished on the basis of colour.
Light coloured - (eg; Ompara Karewa),
Red - hued soil- (eg;Badgam Karewa),

Dark- blackish soil- Known as surhzamin.

In fertility, the surhzamin is rated as the best while the yellow hued soil is regarded as the worst (Lawrence, 1967).

However, the Kashmiri peasant has his own perception of the soil types. He recognizes four main types of soil, *viz.*, gurti, bahil, sekil and dazanlad (Lawrence, 1967; Raina, 1971).

Gurti is a rich soil with high percentage of clay and silt. This soil is fertile and supports good crops. This soil zone is roughly continous with Jhelum flood plain.

Bahil soils are excellent loams with silt, clay and sand. The silt and clay content progressively declines away from Jhelum flood plain. The bahil is a prized soil with very high fertility status.

The sekil soils are having higher sand content. Most of the sekil soils are under forests. It is rich in humus and may yield good crops.

Dazanlad soils are found along the left bank of the Jhelum where there is chronic problem of water logging.X Dazanlad soil is found along the fringe of the swamps. There is one more soil type known as nambal- swampy lands. The soil types of the Kashmir valley are shown in Fig.2.4.

X Raza, M.A. Ahmad and Mohammad, A-(1978).
The reason of the water logging is the low lying condition along the river Jhelum, which is enriched by floods.

Chapter-3
Gelogical Framework

GEOLOGICAL FRAMEWORK

The Jammu and Kashmir state contains one of the finest developments of the stratigraphic succession right from the Archean to Recent, holding a complete sequence of marine Paleozoics, Mesozoics and Cenozoics. A rich fossiliferous geological record is seen in the hills and mountains surrounding the beautiful valley of Kashmir in easily accessible localities.

3.1 REGIONAL GEOLOGY

The stratigraphic sequence of the geological formations with general lithology of Kashmir region is given in Table 3.1 (GSI, 1989). The geological map of the Kashmir region is shown in Fig. 3.1. The lithological description and areal extent of the different formations are given below:

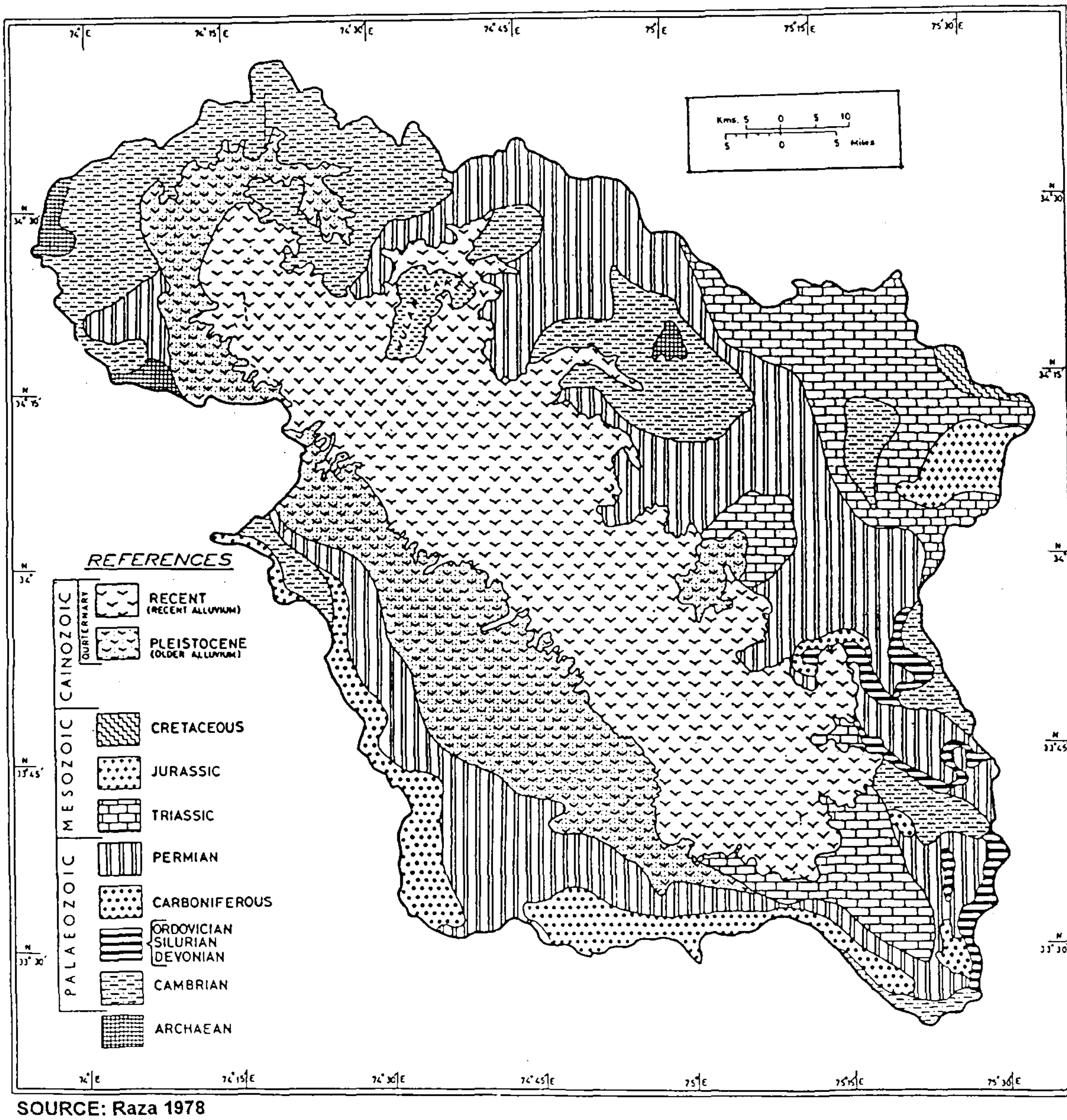
Precambrians- Salkhala formation

In Kashmir the Precambrian rocks are called Salkhala formation (Wadia, 1931). It is considered as the oldest metasedimentary unit of Northern Himalaya, representing the basement complex and constitutes carbonaceous slates, pyritous graphitic phyllite and schist, associated with carbonaceous grey or white limestone, marble, calcareous slate and calcareous schist. It also comprises chloritic, talcosic and sericitic phyllites and schists, garentiferous schists and flagy quartzites. Wadia (1931) observed that severe deformation and high grade metamorphism are additional characteristics of Salkhala formation. The rocks of this formation are intimately associated with granites and gneisses.

Table 3.1: The stratigraphic sequence of geological formation of Kashmir region (GSI-1989).

Geological time Scale		Group and formation	General lithology
Quaternary	Holocene	River terraces and alluvium	Unconsolidated Pebble, boulder, sand and clay
	Pleistocene	Karewa Gp. Nagum Fm. Hirpur Fm.	Silty, clay pebble
1.8my Neogene	Pliocene Miocene		
23my Paleogene	Oilgocene Eocene	Numulitics	limestone and shale (marine facies) grey to purple shale, carbonaceous shale±coal bed (continental facies).
65my	Paleocene		
Mesozoic	Cretaceous Jurassic	Wumuh Fm.	Sand, stone, shale, limestone.
	Triassic Permian	Vihi Gp. Wuyan Fm Khrew Fm Khunamuh Fm. Zewan Fm.	Limestone, dolomite, shale, sand stone, dark grey shale.
243my Palezoic	Carboniferous	Mamal Fm. Panjal volcanics Nishatbagh Fm. Agglomeratic Slate	Predominently volcanics with shale and silt stone, plant beds Quartzite, conglomerate, diamictite, slate.
	Devonian Silurian	Fenestella Shale Syringothyris Lst. Aishmuqam Fm. Muth Fm. Margan Fm.	Limestone, silt stone, shale, variegated silt stone, quartzite, silty and calcareous shale. limestone, quartzite with marine fossils.
570my	Ordovician Cambrian	Karihul Fm. Lolab Fm. Dogra Fm.	Greenish grey sand stone, quartzite, grey and dark silt stone±lst. lst, dolomite, with stomatolite. dark grey shale/slate with quartzite.
	Proterozoic	Salkhala Fm.	Slate, phyllite, quartizite, grey shale, siltsone, lst,±gypsum.
2500my Archean		Not yet recognized	

Fig. 3.1 Geological map of Kashmir valley



SOURCE: Raza 1978

The gneiss intruded in the Salkhala formation has been designated as Central Himalayan Gneiss (Stoliczka, 1866: Mc Mohan. 1882; Middlemiss 1890). These gneisses are acid, felspathic biotite. granite gneisses and are porphyritic. There are also dolerites, amphibolites, pyroxenites within the formation. The outcrops of these oldest rocks are found around the northwestern extremity of the Kashmir valley and portions of the Pir Panjal range.

Dogra slate

These rocks consist essentially of a thick series of phyllitic, black and green coloured, flaggy or massive cleavage slate, interbedded with green, chloritoised, amygdaloidal trap, a product of contemporaneous volcanic action, were designated as the dogra slates by Wadia (1928). The slates show incipient foliation, the original bedding planes rarely distinguishable as bands of different colours have largely been obliterated by the superinduced cleavage planes. The lenticular quartz veins are common. The Salkhalas are overlain by Dogra slates in the western flanks of Pir Panjal range and north western parts of the Kashmir valley with unconformable or thrust contact except in the syntaxial zone where it is gradational. However, the relationship of the Dogra slates with the lower horizons of the Cambrian sequence is obscure (Pascoe, 1959).

Paleozoic

The Kashmir Himalayas is one of the classic areas exhibiting continuous Paleozoic succession with enormous fossil wealth.

The geological, paleontological and petrological observations have been recorded by many workers. However, the authentic geological account was given by Godwin Austen (1866) and Verchere (1866-67), who were the first to introduce Paleozoic stratigraphy. Lydekker (1883) produced first geological map of Kashmir and made the first systematic study of the stratigraphy. The detailed study and systematic mapping was carried out by Middlemiss (1909, 1910, 1911). Middlemiss divided the stratigraphic sequence into two divisions, by making the Agglomeratic slate and Panjal Volcanics as a convenient series for division. The two divisions are: Div. A, below the Panjal Volcanics and Div. B, above the Panjal Volcanics. Wadia (1934) mapped northern part of Kashmir valley including the Pir Panjal. The stratigraphy of SE Kashmir after Middlemiss (1910, 1911) and Wadia (1934) is shown in Table 3.2.

Table 3.2. Stratigraphy of SE Kashmir after Middlemiss (1910, 1911) and Wadia (1934).

Age	Middlemiss (1910-11)	Wadia (1934)
	Div. B.(Above the Panjal Volcanics)	
Triassic	(11) Upper Trias (10) Muschelkhel (9) Lower Trias	
Permian	(8) Zewan formation (7) Gangamopteris beds	Zewan formation lower Gondwana beds
Upper Carboniferous	Panjal Volcanic flows Agglomeratic Slate	Panjal Traps Agglomeratic Slate
	Div. A. (below the Panjal Volcanics)	
Middle Carboniferous	(6) Fenestella Shale (5) Passage beds	Fenestella Shale
Lower Carboniferous	(4) Syringothyris Lst	Syringothyris Lst
Devonian	(3) Muth quartzites	Muth quartzites
Ordovician		
Silurian	(2) Upper Silurian (1) Lower Silurian	fossiliferous slate, quartzose greywacke etc.
	& (?) Cambrian	Obscurely fossiliferous slates, greywackes etc.

Gopender Kumar *et al.*(1981) however, divided lower Paleozoic into following units:

Margan Shale

Karihul formation

Khaiyar formation

Stratigraphically, the lower Paleozoic of Kashmir is not well understood because bulk of the sediments are mostly unfossiliferous and varying degree of matamorphism has made lithostratigraphic correlation difficult. However, the upper Paleozoic is well understood because of the persistent faunal horizons. The upper Paleozoic formations have been described under more or less same litho units by all the workers.

Karihul formation

This formation is named after a village Karihul the best exposed section of Karihul formation is seen along the left bank of the Harpatnar section (North of Harpatner village) South West of the valley.

It consists of an interbeded sequence of greenish grey micaceous sandstone and shale with thin lenticular limestone/dolomite. The fossils reported are a good collection of trilobites of phychoparia species which is of Middle Cambrian age (Gopender *et al.*, 1981). Some primitive brachipods have also been reported.

Margan formation

Margan formation corresponds to the upper Silurian of middle miss, 1910 (Gopender *et al.* (1981); Shah, (1972) proposed the name after the margan pass. The formation overlies the Karihul formation and is conformably overlain by the Muth formation. The green sandy shale calcarenite and green splintery shale form the basal unit of Margan formations (Shah, 1972) and is unseperable lithologically from the underlying greenish grey micaceous siltstone/shale of the Karihul formation. The fauna includes Monograptus species.

Muth Quartzites

The Silurian rocks are overlain by a thick succession of snow white to greenish grey, pinkish orthoquartzite of Devonian age, known as Muthquartzites. It forms a conspicuous topographical feature by making prominent cliffs and precipices. The formation consists of hard quartzite which is generally massive and of granular texture and at places with ferruginous spots. It also contains layers of siliceous limestone and agrillaceous matters. The maximum thickness recorded is 317m. It shows wide development in Baramula, Kupwara and Anantnag districts.

Aishmuqam Formation

This formation is a passage bed between Muthquartzites and Syringothyris Limestones (Gopinder Kumar *et al.* 1981) and consists of quartzite with varying colour from white, grey, purple to blotchy. At places the formation is pebbly and gritty with shale and sandstone partings. Fragmentary plant impressions are found in the upper part.

The Syringothyris Limestone is exposed at Kotsu, Ichhnar and Liwur. The formation yields fossils principally of Brachiopod class. *Syringothyris cuspidata* is a characteristic fossil of the strata from which the formation derived its name. Middlemiss (1910) suggested lower Carboniferous age for this formation because of its similarity to the Lipak series of Spiti.

Passage beds

The Syringothyris Limestone is overlain by a considerable thickness of unfossiliferous rocks. The rocks consist of quartz, sandstone, and shale (Middlemiss, 1910). Petrologically they might be linked with Fenestella Shale above rather than limestone below.

Fenestella Shale

The passage beds of Middlemiss were included in Fenestella Shale by a number of workers. The Syringothyris Limestone is conformably overlain by an enormous thickness (> 609m) of quartzites with intervening layer of generally dark shales, sometime slightly calcareous. It is in the lower part that these shales become principally developed and are fossiliferous whilst towards the middle the shale becomes less conspicuous and without fossils. Towards the upper limit where the formation pass into Agglomeratic Slate, there recurrs another fossil bearing horizon. Fossil *Fenestella* gave rise to the name of this formation. The fossil *Fenestella* possess individual characteristics of its own (Diener, 1915) bearing no relation to lower or upper Carboniferous.

For this reason this formation is placed between lower and upper Carboniferous. Although the most characteristic sections are found on the banks of the Liddar river and at Lehindajjar, the formation with fossils is also well marked in the valley head between SW spurs of Liwapatur station and Krapri, near Buru, and at the head of Kirram valley.

Agglomeratic Slate

The Agglomeratic Slates are pyroclastic slates, conglomerates, and agglomeratic products. They contain pieces of quartzite, slate, porphyry, granites *etc.*, irregularly dispersed in a fine grained greywake like matrix. These are generally unfossiliferous but well preserved fossils have been obtained in Golabgarh Pass. The presence of Fenestella and Protoretepora and their conformable upward passage into the basal Gondwana conglomerate suggest upper Carboniferous age to these rocks.

Panjal Traps

Agglomeratic Slates are overlain by a thick series of bedded andesitic and basaltic traps. They are distinctly bedded and massive. Amygdaloidal and compact bands are common. The lavas are non-porphyritic. The primary constituents are plagioclase and augite in a fine grained semicrystalline ground mass. The ferromagnesium minerals have been chloritized and / or epidotized to give the traps a green colour. The intertrappean beds are also known within the Panjal Traps but fossils are rare. However, some reported fossils from limestone intertrappean do not indicate any definite age. The Panjal Trap is extensively developed in Kashmir valley. The estimated thickness is between 1800 and 2500 m.

Gangamopteris Beds (Lower Gondwana)

In many parts of Kashmir, the Panjal Traps are directly overlain by a series of beds of cherts, siliceous and calcareous shales, thin bedded limestone, flaggy siliceous beds of quartzite with a band of rock known as *Novaculite*. These beds contain fossil impressions of ferns like Gangamopteris and Glossopteris with skeletons of labyrinthodonts and fishes. Wadia (1928, 1934) calls the plant beds as lower Gondwana with both Gangamopteris and Glassopteris flora. The localities where the horizons are found are NE slope of Pir Panjal at Banihal pass, at Golbargash pass, near Gulmarg and at Marhom. The age of Gangamopteris beds is upper Carboniferous to lower Permian.

Zewan Formation

In Zewan, which is a type locality in Vihi district, the Gangamopteris beds are overlain by a series of marine fossiliferous calcareous shale and crystalline limestone. The name 'Zewan formation' has been applied to the entire succession from Gangamopteris beds to lower Triassic beds. The lower part of the Zewan formation is argillaceous but the upper part is calcareous. The lower part of the shale contains the abundance of fossil *Protoretepora*. Over the top of the series there lie thin bands of hard limestone and shales bearing Pseudomonotis, Danubites and other ammonites. Some outcrops are also seen in Liddar valley, Pir Panjal and upper Sind.

Mesozoic

The Paleozoic formation are conformably overlain by Mesozoic formation in the whole of the Himalayas, particularly in Kashmir and Spiti. Because of marked difference in fauna between Paleozoic and Mesozoic the boundary between these can be easily delineated. Cephalopods, which are abundant in the Mesozoic take the place of Brachipod fauna which are abundant in Paleozoic. Of the three epochs of the Mesozoic era, only Triassic is well developed in the Kashmir region.

Triassic

The Triassic of Kashmir consists mostly of a thick series of compact blue limestone, agrillaceous limestone and dolomitic limestone and covers a large area of Kashmir. A superb development of limestone and dolomites of this system is exhibited in a series of picturesque escarpments and cliffs forming the best part of the scenery north of the river Jhelum. Middlemiss (1910) divided the Triassic horizons of Kashmir into 3-broad units (Table 3.3).

Table 3.3. Triassic horizons of Kashmir (after Middlemiss ,1910).

Upper Trias (>500m)	Unfossiliferous massive limestone. Spiriferina stracheyi and S. Hauri zones. Lamellibranch beds. Ptychites horizon; Sandy shales with calcareous layers. Ceratite beds;Sandy shales with calcareous layers. Rhynchonella Trinodosibeds;Sandy shales with calcareous layers.
Muschalkhalk (About 274m)	Gymnites and ceratite beds;Sandy shales with calcareous layers. lower nodular limestones and shales. interbedded thin limestone, shales and sandy limestone.
Lower Trias (over 91m)	Hungarite shales. Meekoceras limestone and shales. Opheceras limestone.

Lower Triassic

All the three zones of lower Triassics, the Otoceras, Ophiceras and Meekoceras are developed in Vihi district of Kashmir. These are well exposed in the Sind and Liddar valley. Good sections have been found near Pastana and Lam (Tral).

Middle Triassic (Muschalkhalk)

The middle Trias, also known as Muschalkhalk are visible at Pastna, Khrew, Khunmu, above Pahalgam in the Liddar valley and in some tributary valleys of upper Sind. The Muschalkhalk consists of buff coloured thin bedded limestone with thin intercalations of sandy limestone and shale with a 100 feet thick grey thin bedded limestone at the base. These are overlain by pale nodular limestone and conspicuous horizons of red and grey slaby limestones rich in cephalopod fossils.

Upper Triassic

The middle Triassic pass upward into more massive beds of the upper Triassic limestone of a few thousand meters thick and cover much wider area than the lower and middle units. These comprise pale grey limestones and dolomites with occasional quartzite layers which in some sections pass upwards into dark slate and thin limestone of Jurassic age.

Jurassic

The Jurassic formations are developed in north side of Banihal Pass of the Pir Panjal. They are associated in a tightly compressed syncline in the upper Trias. The system consists of a series of limestone, sandstone and shale. The Jurassics are also found near Baltal, Sonmarg and in the Amarnath valley.

Cretaceous

The formation of Cretaceous are well distributed in the Ladakh district of Kashmir.

They are white limestones containing *Gryphaea vesiculosa.* Granites, Pyroxinites, and other igneous rocks are known to be intrusives into the Cretaceous limestones and shales.

Tertiary

In Kashmir region only the Eocene and Murees are present. The Eocene comprising dense Jaspery quartzites replacing limestone, carbonaceous and pyritous shale, grey calcareous shale and fossiliferous limestone and unfossiliferous red,purple and green shales with sandstone bands are found overlying the Triassic limestone in the Uri area.

The Murees of Punch area of Jammu are continued to the Uri area of Kashmir, where they have faulted contact with the underlying numulitic limestone.

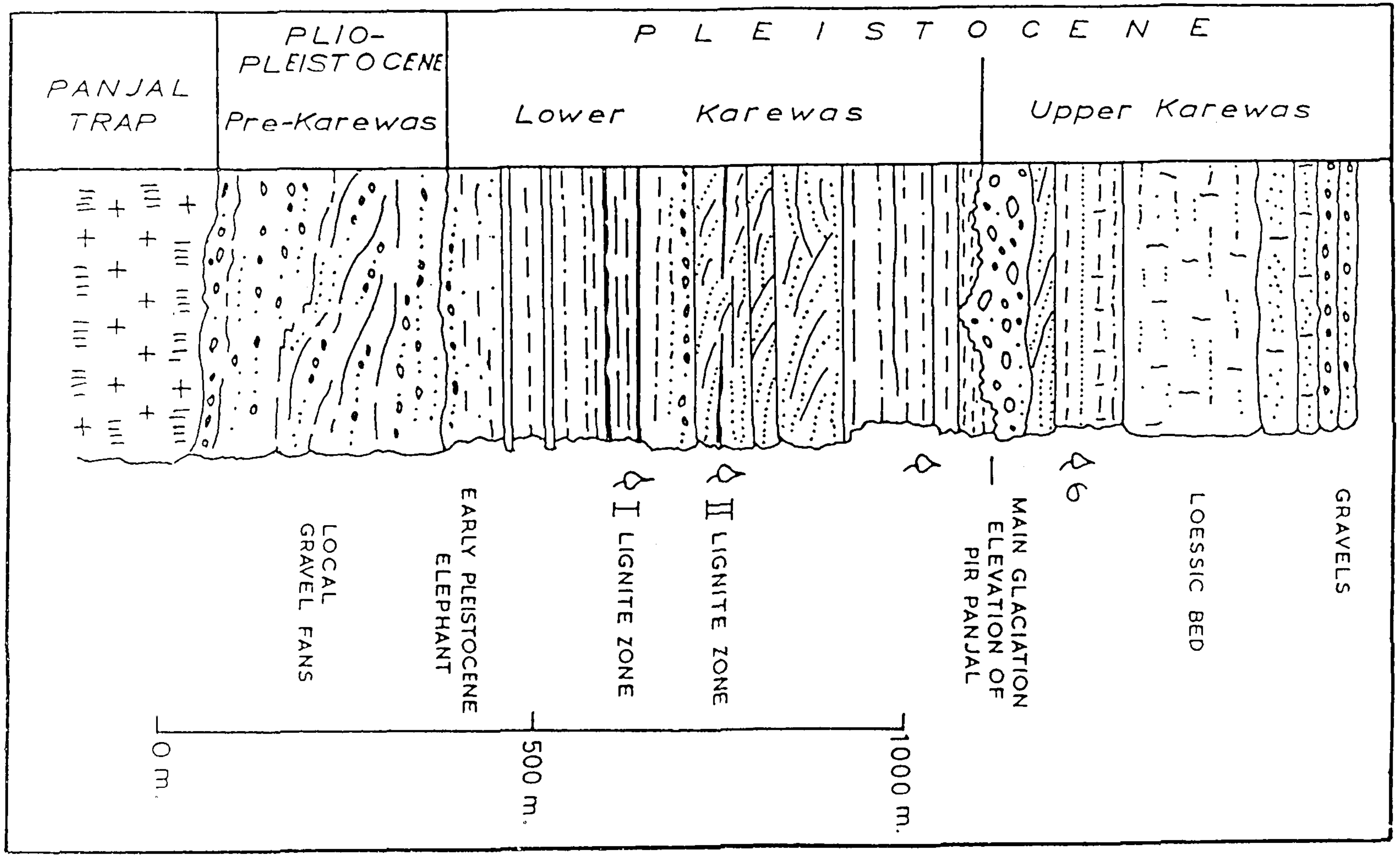
Quaternary (Karewa Group)

Godwin Austen (1864) was the first to take interest in the detailed geology of the Karewa deposits. Drew (1875), Lydekker (1878), Middlemiss (1911, 1924), de Terra and Paterson (1939), Wadia (1914) and Bhatt (1975) are the other workers who had worked on the Karewa deposits.

During the Pleistocene period Kashmir had witnessed four major glaciation which were separated by the inter glacial periods of humid and temperate climate. Of these interglacial periods, the first one synchronised with the appearance of a wide spread lake, which occupied every bit of the present day Kashmir valley. The non-deposition during glacial phases and active deposition during the interglacial phases is well preserved in these deposits. These alternations were simultaneous with the intermittent uplift of western Himalayas, which resulted in a thick pile of deposition in the lake unless it was drained off at Baramulla, through which Jhelum flows at present. The deposits thus formed occupy nearly half of the area of present day Kashmir and presently range in altitude from 1600m in the Jhelum to over 3350m on the slopes of Pir Panjal. They are known as Karewa deposits. The term Karewa is of Kashmiri origin. It means flat-topped hillock. The stratigraphy of the Karewa beds is shown in (Fig. 3.2). Karewa Group have been divided into lower and upper Karewas.

Lower Karewas (Hirpur Formation): The lower Karewas are mostly argillaceous, light grey, sandy, dark grey clays, coarse to fine grained greenish sands but have the gravel beds at the base containing most of the lignite of the Karewas and yield a number of fossils of Equs, Elephus, Bos, Sus, Rhinoceras, cervus, Felis, fish and bird bones and several leaf impressions. According to Wadia (1941) the basal lower Karewas are preglacial in origin and their top portions even represent the debris of second Ice advance. The original thickness of lower Karewas is estimated to be about 1675m.

Fig. 3.2 Stratigraphy of the Karewa beds



SOURCE: D.N.Wadia 1951

Upper Karewas (Nagum Formation): Nagum formation are separated from the Hirpur formation by an unconfirmity representing an erosional interval. According to Wadia (1941) about 600m of the lower Karewas were eroded from the crest of the anticlinal folds. The upper Karewas are mostly arenaceous and comprise mainly of the continental and lacustrine deposits consisting of the gravel facies, the lacustrine facies and the loess facies are characterized by the absence of lignite and by rare fossil content. The Nagum formation starts with gravel facies which according to deTerra represents second glacial and interglacial stage. The lacustrine facies comprise the pale, yellow laminated marls and silts with medium to coarse grained calc grits and varved clays. The lacustrine facies is overlain by the loess facies, which comprise brown granular loams occuring as cappings over the river tarraces. The thickness of upper Karewas in full is 610m. The general lithostratigraphy of Karewa group in Kashmir valley is shown in Table 3.4 (Bhatt, 1989).

Recent to sub recent

The valley of Kashmir is an alluvium filled basin a large part of which is of recent formation deposited by the river Jhelum and the adjoining *nalas* of the Kashmir valley. These deposits include alluvial tracts, flood plains, river terraces, and talus and scree fans.

Table 3.4 The general lithostigraphy of Karewa group in Kashmir valley

Formation	Member	Lithology	Thickness (m)
Alluvium (Holocene) Dilpur (Upper Pleistocene)		Sand and silt Continental loess and reworked loess	20-50
Nagam Fm. (Middle Pleistocene)	Shupiyan/Rampur Krungas	Yellow silt, grey clay, calcareous layers and sand with, conglomerates in the marginal areas (Ferrestrial, braided stream and lake delta environment)	40-135
		Unconformity	
Hirpur formation (Pliocene to lower Pleistocene)	Methowain	Grey clay, silt lignitic mud, sand and conglomerate (Lake delta environments with braided stream as sub-environment)	400
	Rembiara	Conglomerate (alluvial fan and braided stream environment)	200
	Dubjan	Grey clay, silt, lignitic mud, lignite and green sand (Lake delta environment)	600
		Unconformity	
Pre-Karewas		Mostly Paleozoic and Triassic basement	

3.2 GEOLOGY OF THE DAL LAKE CATCHMENT AREA

The description of the geological formations of the Dal Lake catchment areas (discussed in regional geology) is given below;

Cambro-Silurian

It consists of pyritiferous mudstone and slate; greywacke, banded sandstone and sandy phyllite, and shale which is occasionally calcareous and sandy. It is exposed towards the northern side of the catchment area.

Agglomeratic slates

These are pyroclastic slates, conglomerates and agglomeratic products and contain pieces of quartzite , slate porphyry granite etc, irregularly dispersed in a fine grained greywake like matrix.

Panjal Traps

Panjal Traps are extensively developed in the catchment of Dal lake and consist of bedded andesite and basaltic traps. They are distinctly bedded, massive, amygdaloidal and compact. Plagioclase and augite are the common phenocrysts within the semicrystalline groundmass.

Triassic Limestone

Triassic Limestone is also widely developed in Dal Lake catchment area and consists mostly of a thick series of compact blue limestone, agrillaceous limestone and dolomitic limestone. A superb development of limestone and dolomites of this formation is exhibited in a series of picturesque escarpments and cliffs forming the best part of the scenery north of the river Jhelum.

Karewas

The deposits occupy nearly half of the area of present day Kashmir and presently range in altitude from 1600m in the Jhelum to over 3350m on the slopes of Pir Panjal.The lower Karewas are mostly argillaceous, light grey, sandy, dark grey clays, coarse to fine grained greenish sands but have the gravel beds at the base containing the lignite. The upper Karewas are mostly arenaceous and comprise mainly of the continental and lacustrine deposits consisting of the ravel facies, the lacustrine facies and the loess facies without lignite.

Alluvium

The low lying areas surrounding the rivers/nallas are covered by alluvium.

As the topic is mainly concern with environmental aspects and due to time constrain this aspect has not be taken in account while considering the pollution assessment and their significance in Dal Lake.

Chapter-4

Texture and Geo-chemical Assessment of Dal Lake Sediments

TEXTURE AND GEOCHEMICAL ASSESSMENT OF DAL LAKE SEDIMENTS

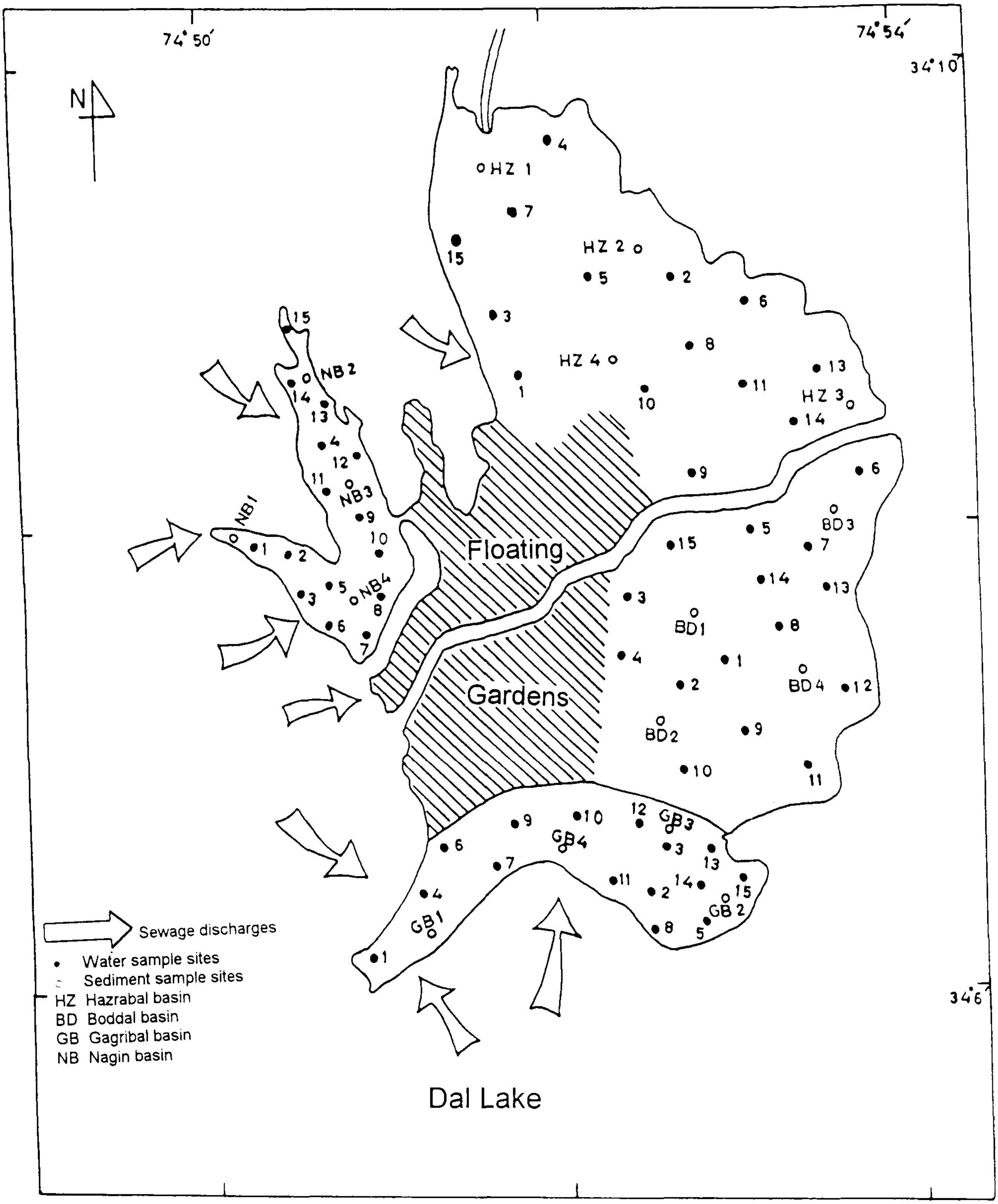
Lacustrine deposits have long been recognized as the recipients of both mineral and organic matter that is transported to the lake from the drainage basin, as well as matter which forms and settles from within the lake body. So any lake water pollution assessment program would be incomplete without the proper study of its sediments. Lacustrine sediments at the water column play an important role in the pollution scheme of the lake ecosystem as they are less susceptible to flow conditions and when the heavy effluent loaded water enters the lake body, various physico-chemical reactions take place and a large portion of effluents either settles down or is adsorbed by the sediments. The concentration and abundance of these chemical constituents in the sediments reflect the occurrence and abundance of these metals in rocks and mineralized deposits of their catchement areas and the anthropogenic sources. However, at present the anthropogenic contribution to the heavy metal load of the lakes equals or exceeds the amount released by weathering processes. The elemental concentration of sediments not only depends on anthropogenic and lithogenic sources, but also upon the texture, organic content, mineralogy and depositional environment of sediments (Presely *et al* 1980). In order to gain a proper appreciation of the role of sediments within the lake ecosystem, it is essential to understand the importance of relationship between the particle size, composition and geochemical behaviour of various chemical constituents. It is generally believed that fine grained sediments contain higher concentration of metals because of their more surface area as compared to coarse ones (Gibbs 1977; Salomons and Forster 1984; Biksham and others 1991). Increased concentration of metals in coarse sediments are also observed and it is believed that coarse particles may better document anthropogenic inputs because of their limited transport and larger residence time at any particular site (Tessier and others 1982; Salomons and Foprstner 1984). Chemical nature and behaviour of various elements in lacustrine environment mainly depends upon the geology of catchment area, soil type, anthropogenic inputs and other sediment water interactions. In order to infer the different sources of the metal pollution, it is very important to assess simultaneously both the grain size distribution and the major and trace element geochemistry for natural and anthropogenic inputs in lake sediments.

4.1 METHODOLOGY

4.1.1 Sample Collection

The aim of sampling is to collect desirable amount of material quite enough for the analysis of different parameters. For grain size and geochemical analyses twenty sampling sites were selected on the basis of depth and tropical status throughout the whole stretch of Dal Lake (Fig. 4.1).

Fig. 4.1 Location map showing sampling sites



Sediment samples were collected seasonally (Four times a year) with a scoop from shallower sites and by means of an Ekman dredge from deeper sites, were air dried and pulverized in a mortar and rubber tipped pestle. The crushed material was sieved through 2mm mesh and stored in polythene bags for analytical use. These samples were brought to the Geochemical laboratory, Department of Geology, A.M.U. Aligrah, where major portion of geochemical analysis was carried out.The trace elements were analysed in Wadia Institute of Himalayan Geology (W.I.H.G) Dehra Dun and the grain size analysis was carried out at Forest and Soil division in Forest Research Institute (F.R.I), Dehra Dun.

4.1.2 Analytical Technique

Particle size analysis was carried out with the help of Hydrometer technique to separate silt, sand and clay fractions and the results were expressed in percentage composition. Geochemical analysis of the sediments was carried out by decomposition of each sample by HNO_3, HCL, H_2SO_4 and HF mixture to form solution A and solution B. Solution A was prepared by decomposing 0.1gm of sediment sample by fusion with NaOH (16 pellets) for five minutes in nickel crucible. The mixture was cooled to room temperature, bleached with distilled water, covered with lid and allowed to stand over night. The solution was taken into a beaker and acidified with, 20ml of 1:1 HCl and boiled for 10 minutes on a hot plate to get clear solution. After cooling solution was taken into

1000ml volumetric flask and volume made up to the mark by adding distilled water. It was stored in a polythene bottle and used for determining the concentration of Si and Al, while the concentration of elements like Na, K, Ca, Mg, Ti, P, Fe and Mn was determined by using solution B, which is prepared by taking 0.5mg of sample into a platinum crucible supplemented with one or two drops of concentrated H_2SO_4 and 30 ml of HF. The crucibles with lid were kept on a steam bath. After one hour the lid was removed and heating was continued till the sample completely dried up. Crucible was taken out and 10ml of dilute HNO_3 was added to it. The whole content was washed thoroughly in the beaker and heated for 15 minutes to get a clear solution. The solution was then cooled to room temperature and made up to 250ml in volumetric flask and stored in polyethylene bottle for analytical use. For trace element analysis solution B was diluted up to 50ml only and the standards and blanks were prepared in similar way.

X Atomic absorption spectrophotometer was used for the estimation of Si. Al. Ca, Mg, Fe, P,Ti. Mn, Zn, Cu, Ni. Pb. Co and Na. K was estimated by flame emission photometer and the results were expressed in $\mu g/g$ (Appendix 1-a,b,c and d).

4.2 GRAIN SIZE DISTRIBUTION AND TEXTURE

In the past few decades, textural studies of unconsolidated sediments have been a subject of intense research as these studies are

X The details of the instrumental function is not so important in describing the analytical results, however, the methodology adopted in the analyses of different components has been delt in this chapter under the subheading of Analytical Techniques.

sediments (Pasrega, 1964; Sahu, 1964; Visher, 1969 and Sly *et al.* 1982). One of the fundamental approach in studying the sediment size and texture parameters is to facilitate the comparison of sediments and to aid in the correlation of sediment types to infer their environment of deposition (Inman, 1952). Sediment texture bears a close relationship to deposition conditions, topography, wave and current pattern (Rao, K.P. et al. 1997; Singh, L.J.C. et al. 1998). Further, knowledge of sediment texture is one of the efficient tools to differentiate various depositional environments of ancient as well as recent sediments (Mason and Folk, 1958; Friedman, 1961; Moiola *et al.*, 1974 and Nordstrom, 1977). Texture also controls the mineralogical and chemical composition of sediments.

The results of the grain size analysis of Dal Lake sediments, based on twenty sampling sites from the major feeding channel (Telbal nala) and the four basins (Hazratbal basin, Boddal basin, Gagribal basin and Nagin basin) is given in Table 4.1.

4.2.1 Inflow Channel

The sediment samples collected from major inflow channel Telbal nala recorded low proportion of sand (both coarse and fine) at site IF2 being 7.2% and a comparatively high proportion of the sand (19.4%) at site IF4, where as the site IF1 and IF3 of the same feeding channel recorded 10.2% and 11.7% of sand respectively, thereby the proportion of sand gradually increased down stream.

Table 4.1: Grain size distribution and texture of Dal Lake sediments (Percent Composition)

Lake Site	Coarse sand%	Fine sand%	Coarse silt%	Fine silt%	Clay %	Texture
IF1	3.8	6.4	47.5	27.1	15.2	Silty loam
IF2	3.3	3.9	31.1	21.5	40.2	Silty clay
IF3	5.2	6.5	34.7	28.5	25.4	Silty
IF4	6.8	12.6	45.2	19.2	16.2	Silty
HZ1	19.5	22.6	28.3	17.1	12.5	Loam
HZ2	3.2	6.5	45.3	24.2	20.8	Silty
HZ3	12.1	17.4	34.8	27.6	8.1	Silt loam
HZ4	3.5	8.6	25.5	20.7	41.7	Silty clay
BD1	3.7	6.4	34.5	25.2	30.2	Silty clay loam
BD2	3.8	5.4	53.2	22.4	15.2	Silty
BD3	3.2	6.5	29.6	16.8	43.9	Silty clay
BD4	4.6	6.3	40.7	32.6	15.8	Silyt
GB1	14.2	19.4	33.1	23.8	9.5	Silty loam
GB2	4.7	7.5	29.4	37.8	20.6	Silty
GB3	5.7	4.4	39.3	30.2	20.2	Silty
GB4	14.7	16.5	37.2	22.4	9.2	Silty loam
NB1	4.7	6.8	45.4	28.8	14.3	Silty
NB2	3.6	3.5	34.4	27.9	30.7	Silty clay loam
NB3	5.6	4.6	40.5	19.2	30.1	Silty clay loam
NB4	13.9	7.6	39.2	30.1	9.2	Silty

The over all percentage contribution of sand in the inflow channel was quite low as compared to silt and clay .A low content of 15.2% clay was obtained at site IF1 (upstream) where as coarse and fine silt contribution was 47.5 % and 27.1% respectively (Table 4.1). On the other hand, the site IF2 recorded high values of clay (40.2%), course silt (31.1%) and fine silt (21.5%). But towards the Hazratbal basin, both the downstream sites IF3 and IF4 recorded again a high silt content as compared to sand and clay which accounted for about more than 60% of the total (Fig 4.2a). In general the sediment texture of the whole inflow channel showed very high proportion of silt (63.71 %) , moderate proportion of clay (24.25%) and very low proportion of sand (12.13%) (Fig. 4.3a).

4.2.2 Hazratbal Basin

The proportion of sand obtained along the whole stretch of inflow channel up to the mouth of Hazratbal basin was less than 20%. But the samples collected within the vegetational stands of Hazratbal basin (HZ1) showed the maximum proportion (42.1%) of sand (both coarse and fine), followed by coarse silt (28.3%), fine silt (17.1%) and clay (12.5%). In contrast, the deep water site of the Hazratbal basin (HZ4) recorded the highest clay content (41.7%), the coarse and fine silt at these sites were 25.5 % and 20.7% respectively. Invariably the highest content of silt (69.5%), comprising of coarse silt (45.3%) and fine silt (24.2%), was recorded at shallower site (HZ2) with sand and clay contributing 9.7% and 20.8% respectively (Table 4.1).

Fig. 4.2a. Spatial percentage concentration of grain size in Inflow channel sediments.

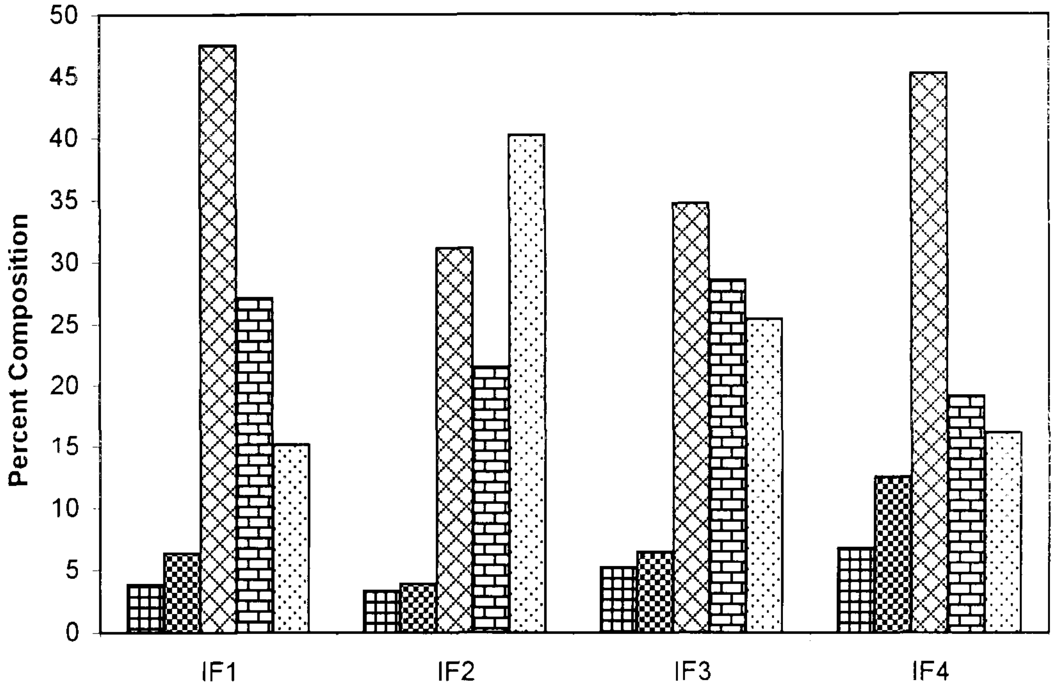


Fig. 4.2b. Spatial percentage concentration of grain size in Hazratbal basin sediments.

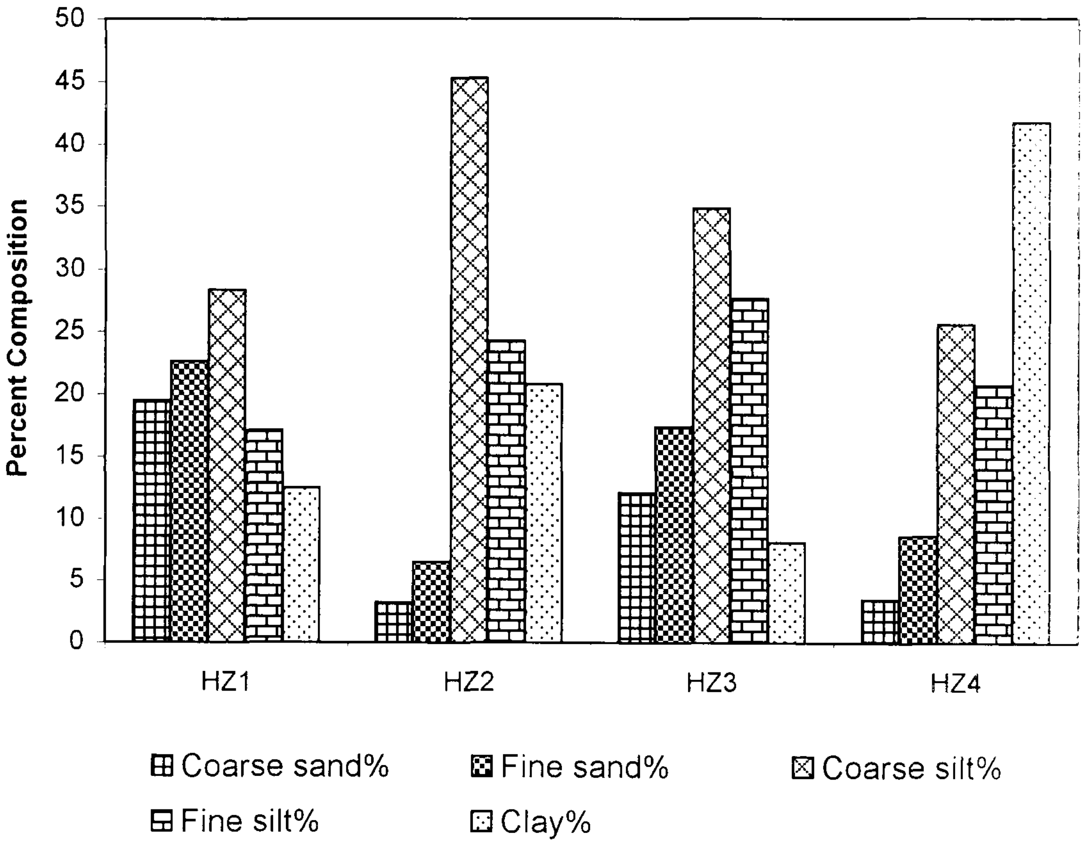


Fig.4.3a Relative percentage concentrarion of grain size in Inflow channel sediments.

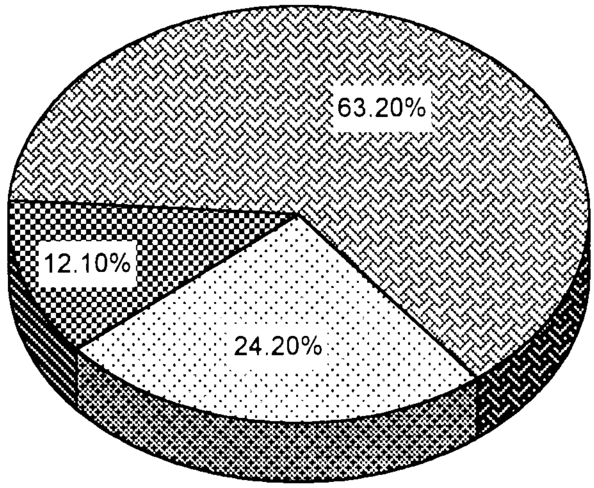
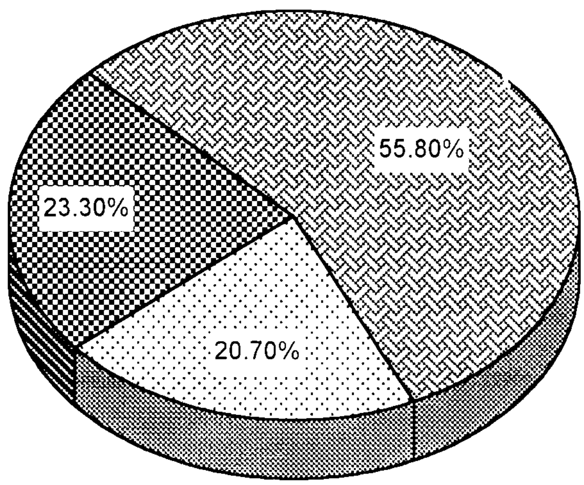


Fig.4.3b Relative percentage concentrarion of grain size in Hazratbal basin sediments.



At the near shore site of Hazratbal basin (HZ3), the contribution of silt was again significant, being 62.4 % (34.8% coarse silt + 27.6% fine silt), but the contribution of clay was very low (8.1%) as against sand 29.5% (Fig.4.2b). On the basis of granulometric analysis the sediments of Hazratbal basin over all recorded 23.35% sand, 55.87% silt and 20.77% clay.(Fig.4.3b).

4.2.3 Boddal Basin

The Boddal basin sediments showed high values for coarse silt content in inshore regions which progressively decreased towards offshore regions. The littoral zones (sites BD2 and BD4) contributed high coarse silt, 53.2% and 40.7% for two sites respectively (Table 4.1), where as clay content at these very sites hardly exceeded 16% of the total. The noteworthy feature of Boddal basin as compared to other basins is a uniform distribution of sand particles at all the sampling sites not exceeding 11%. In the deeper regions (sites BD1and BD3) an abundance of clay content being 30.2% and 43.9 % was recorded for the two sites respectively (Table 4.1). The contribution of coarse silt at these sites was again comparatively low. The results so far obtained at shallower sites (BD2 and BD4) showed a reverse trend, recording high coarse silt content and low clay content (Fig.4.2c).The grain size distribution of the whole Boddal basin showed some similarity with the

The main source of sediment load is from Tail bal Nala in Boddal basin. As the sediment load firstly settles down in Hazarat bal basin with high flow condition. This high flow diminishes on moving towards Boddal basin and turn into steady flow which is mainly responsible for the uniform distribution of sediment load in Boddal basin.

Fig. 4.2c. Spatial percentage concentration of grain size in Boddal basin sediments.

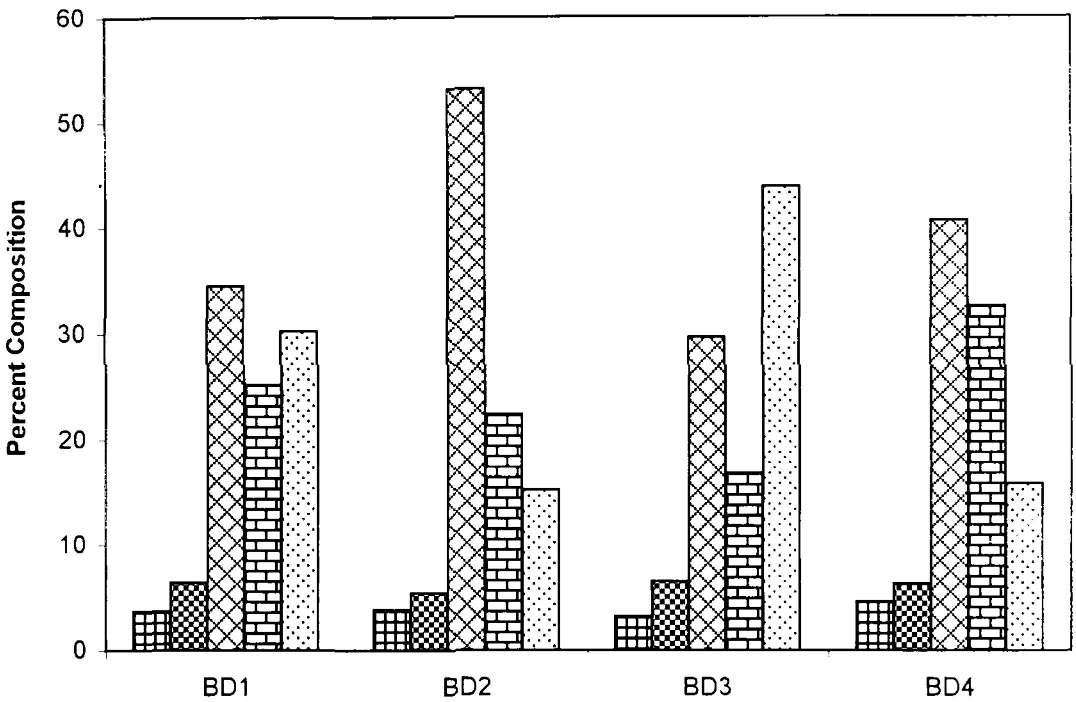


Fig. 4.2d. Spatial percentage concentration of grain size in Gagribal basin sediments.

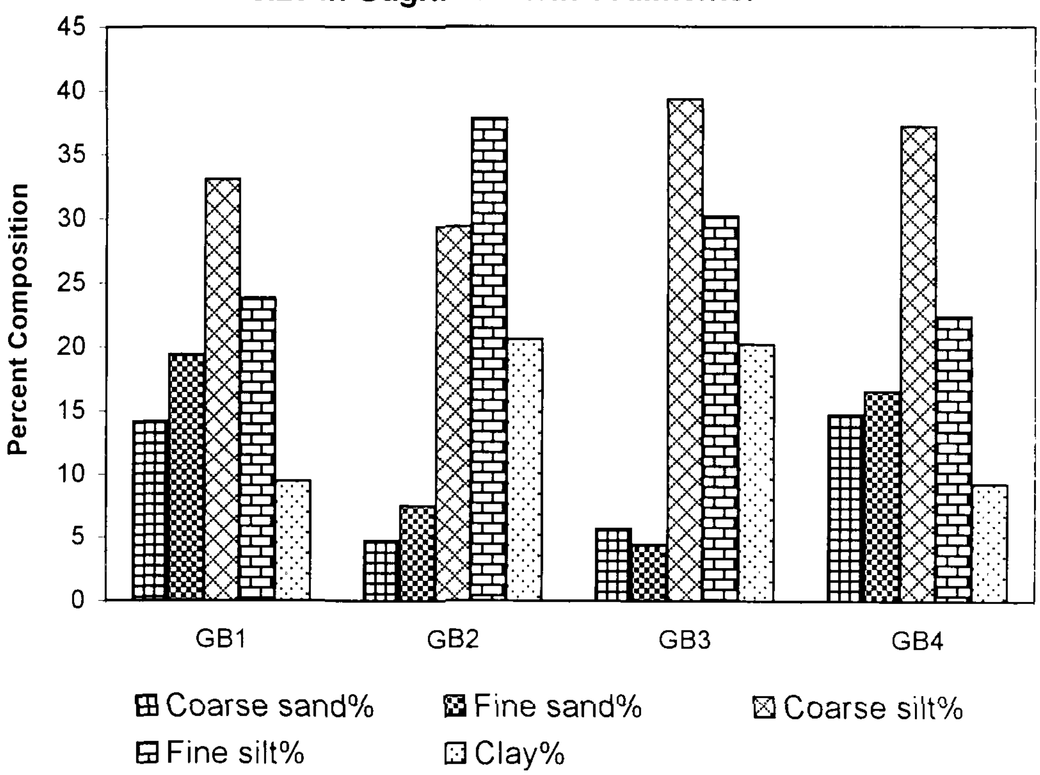
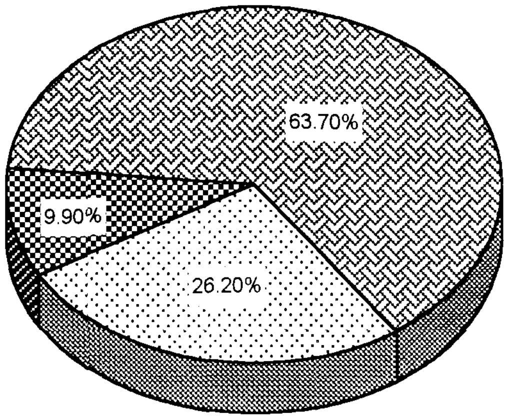
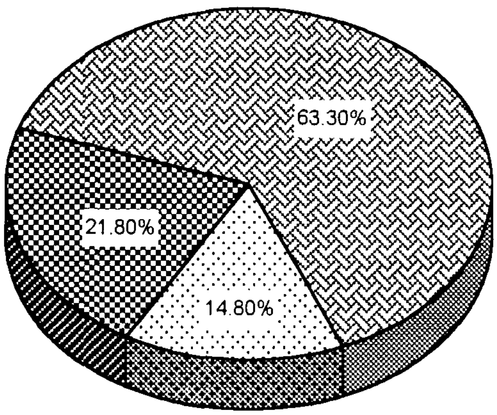


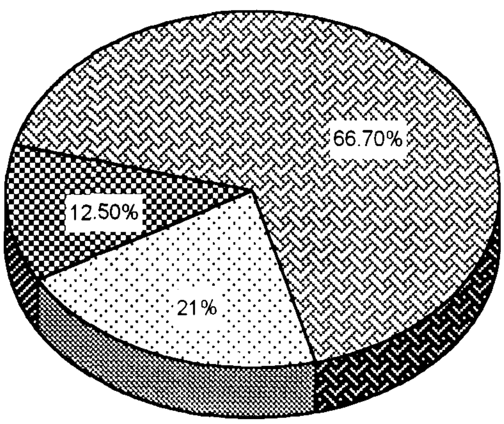
Fig.4.3c,d and e. Relative percentage concentrarion of grain size in Dal Lake sediments.



Boddal basin



Gagribal basin



Nagin basin

Sand% Silt% Clay%

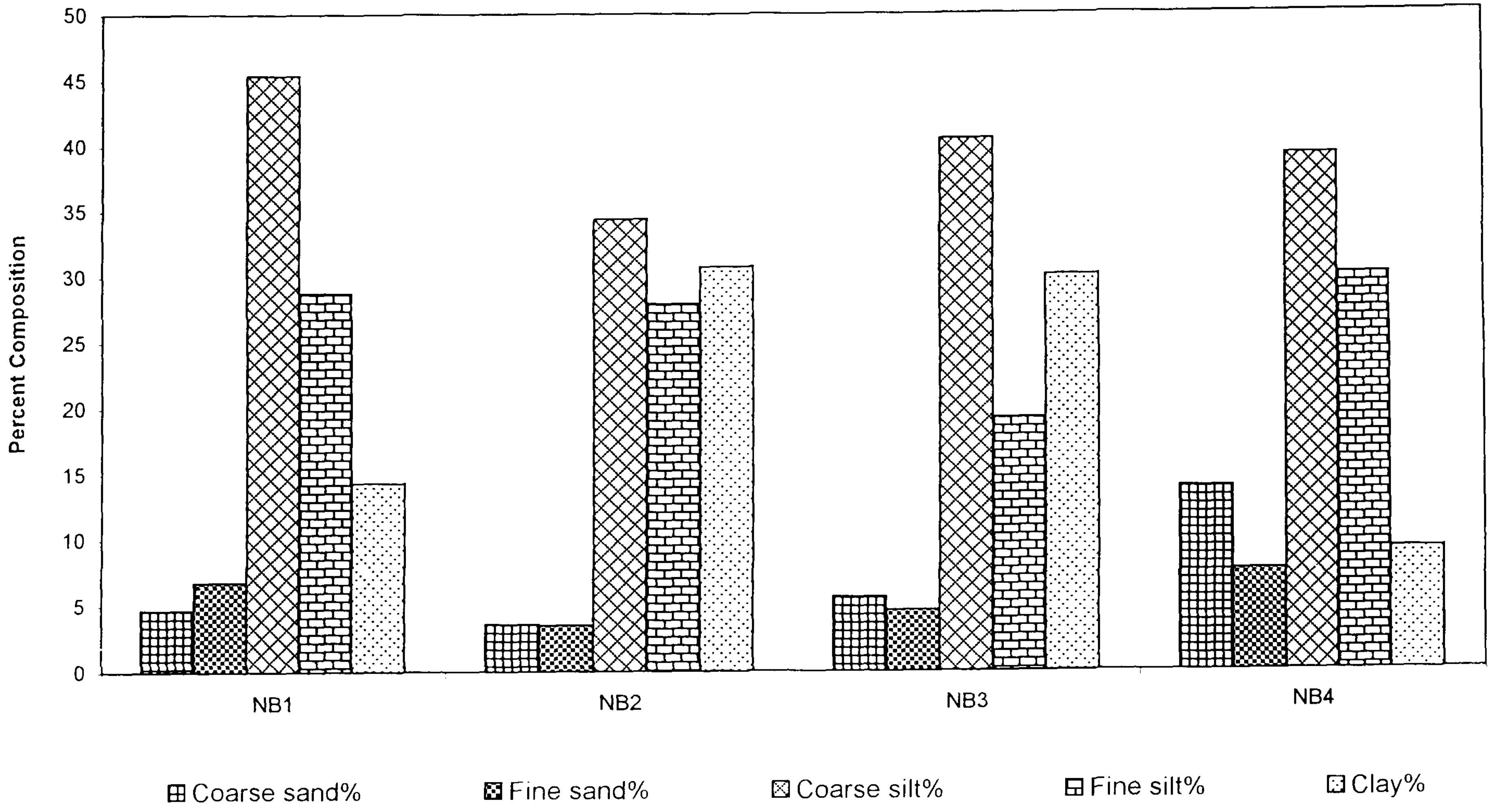
4.2. 4 Gagribal Basin

The data on the particle size distribution in the sediments of Gagribal basin close to the houseboat region showed abundance of sand particles which contributed 33.6% and 31.2% at GB1 and GB4 respectively (Table 4.1). Correspondingly the contribution of clay was very low at these sites, not exceeding 10% at both sites. The proportion of fine silt was also low as compared to the other sites of the basin. Sites, GB2 and GB3 showed higher proportion of silt which accounted for 67.2 % and 69.5% respectively, leading to low contribution of sand particles. These sites also registered comparatively high values for clay. being 20.6% for GB2 and 20.2% for GB3 (Fig. 4.2d). The particle size distributional pattern of sediment grains of Gagribal basin showed some degree of similarity with that of Hazratbal basin as the sand silt and clay were recorded in a ratio of 21.82 : 63.30:14.87(Fig.4.3d).

4.2.5 Nagin Basin

The Nagin basin sediments showed lower sand content in comparison to Hazratbal and Gagribal basins. The deep waters of Nagin basin (NB2 and NB3) depicted high clay content which was about 30% but the shallow region (NB1) recorded only 14.3% clay .Of all the four sampling sites of the basin, the macrophytic site (NB4) had lowest clay content (9.2%) which correspondingly showed high silt content 69.3% and comparatively high sand content 21.5% (Fig.4.2e). However, very high silt content (74.2%) was recorded at NB1, being the shore site.

Fig.4.2e. Spatial percentage concentration of grain size in Nagin basin sediments.



The coarse and fine silt at site NB2 was 34.3% and 27.4% and for site NB3 it was 40.5% and 19.2% respectively, where as for NB1, it was 45.4% and 28.8%, respectively. Further, the coarse silt and fine silt contributed 39.2% and 30.1% respectively at the site NB4. Overall in the Nagin basin high proportion of silt (66.7%),moderate proportion of clay (21.0%) and very low proportion of sand (12.5%) was recorded (Fig. 4.3e).

4.2.6 Textural Classification And Statistical Measures of Grain Size Data

Ternary plots as per Shepard (1954) (Fig. 4.4a) shows that majority of the samples fall in the fields of clayey silt and sandy silt, besides a few samples fall in the field of silt. Among the five study sites only inflow channel sediments show distinct texture of clayey silt whereas rest of the study sites show mixed texture. Same conclusions were drawn from ternary plot of Folk (1984) (Fig. 4.4b).

Table 4.2 depicts the distribution of mean grain size (Mz) of four basins and an inflow channel of Dal lake. On an average the grain size varies from 3.2ϕ to 4.6ϕ. The highest values (4.3ϕ to 4.6ϕ) are recorded in inflow channel whereas the lowest values (3.2ϕ to 3.6ϕ) are recorded in Gagribal basin. On the other hand the sediments of around 4.0ϕ mean sizes are distributed in the rest of the basins of the Dal Lake.

Fig.4.4a. Textural classification of Shephard (1954).

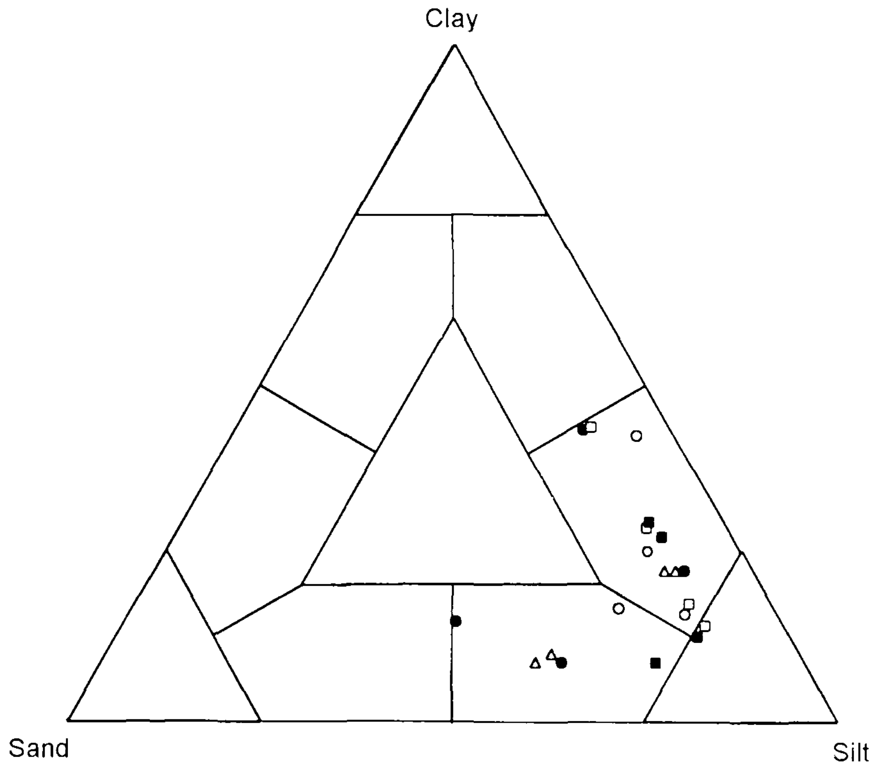
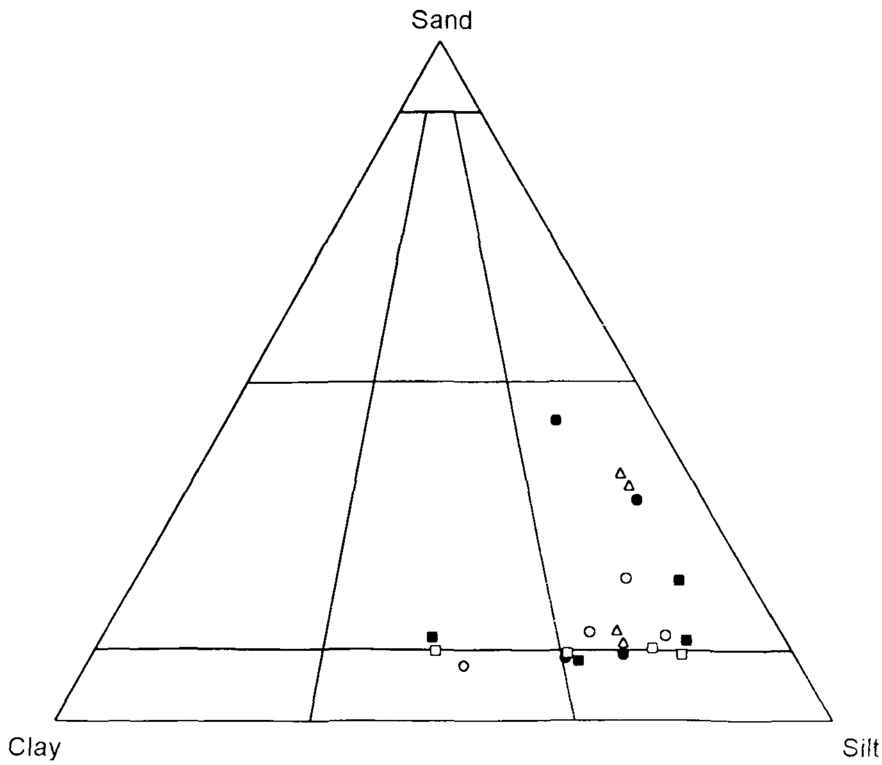


Fig.4.4b. Textural classification of Folk (1984).



○ Inflow channel □ Boddal basin ■ Nagin basin
● Hazratbal basin △ Gagribal basin

Table 4.2: Textural parameters of Dal Lake sediments.

Lake site	Mz	σ_I	SK_I	KG_I
IF1	4.6	2.0	-0.27	1.2
IF 2	4.3	1.9	-0.29	1.3
IF 3	4.5	2.1	-0.26	1.15
IF 4	4.0	2.1	-0.28	1.29
HZ1	3.8	3.0	-0.08	0.84
HZ2	3.6	3.1	-0.05	0.89
HZ3	3.2	3.0	-0.12	0.79
HZ4	3.5	3.0	-0.06	0.82
BD1	4.4	2.2	-0.16	1.0
BD2	4.3	2.1	-0.12	1.12
BD3	4.4	2.2	-0.14	1.21
BD4	4.2	2.0	-0.15	0.96
GB1	3.6	2.3	-0.07	0.89
GB2	3.2	2.1	-0.04	0.73
GB3	3.4	2.2	-0.06	0.83
GB4	3.3	2.1	-0.05	0.79
NB1	3.9	2.3	-0.18	1.1
NB2	3.6	2.2	-0.15	0.95
NB3	3.4	2.1	-0.12	0.78
NB4	3.8	2.3	-0.17	1.05

Standard deviation (σ_I) is a measure of the sorting characteristics of sediments. Standard deviation values in the sediments of Dal Lake ranged from 1.9 ϕ to 3.0ϕ, higher values being conspicuous from the Hazratbal basin and lower values from inflow channel. On the other hand the rest of the basins i.e., Boddal, Gagribal and Nagin basin showed moderate values of standard deviation. It is clear from the values of (σ_I) (Table 4.2). That all the sediments collected from the different basins are poorly sorted. The poorly sorting nature of sediments is apparently due to the mixing of the modern sediments with relict sediments in the complex hydrological flow system of Dal Lake.

Skewness values (SK_1) in the sediments of Dal lake varied between – 0.29ϕ to - 0.04ϕ (Table 4.2). The sediments are grouped into near symmetrical with skewness values of around – 0.08ϕ to – 0.04ϕ recorded from Hazratbal and Gagribal basins and coarse skewed with skewness values from -0.29ϕ to -0.12ϕ recorded from Boddal, Nagin and inflow channel. The coarsely skewed sediments have developed relatively under high energic condition areas near the mouths of the inflow streams whereas near symmetrically skewed sediments have developed under relatively lower energy conditions.

Kurtosis (KG) indicates the peakedness of the size distribution and relates to the normality of the distribution. The kurtosis (KG) values in lake sediments ranged from 0.73ϕ to 1.3ϕ, the Hazratbal and Gagribal basin sediments exhibit platykurtic nature whereas the inflow channel Boddal and Nagin basin sediments showed leptokurtic nature which indicate the high silt deposition by the inflow channel.

Although the binary plots between grain size parameters did not show a pronounced relationship. The binary plot between mean size and (σ_I) (Fig. 4.5a) and between (Mz) and (SK) (Fig. 4.5b) shows that for a wide range of mean size values the grains remain poorly sorted and nearly symmetrical skewed. The bivariate plot between Mz and KG Fig. 4.5c with a slight increase in grain size, the kurtosis of the sediments changes from platykurtic to leptokurtic.

The binary plots between (SK) and (σ_I), (SK) and (KG) and (σ_I) and (KG) show some significant trends (Fig. 4.5d,e,f), the plot between (SK) and (σ_I) show a trend in which sorting of the sediments deteriorates with increase in skewness values. In the (σ_I) and (KG) plot most of the samples concentrate within a narrow field and the kurtosis of the sediment tend to become leptokurtic with a decrease in the standard deviation values whereas the sediments show normal kurtosis towards the negative end in the SK-KG plot.

Fig. 4.5a Bivariate plot of mean size versus graphic standard deviation

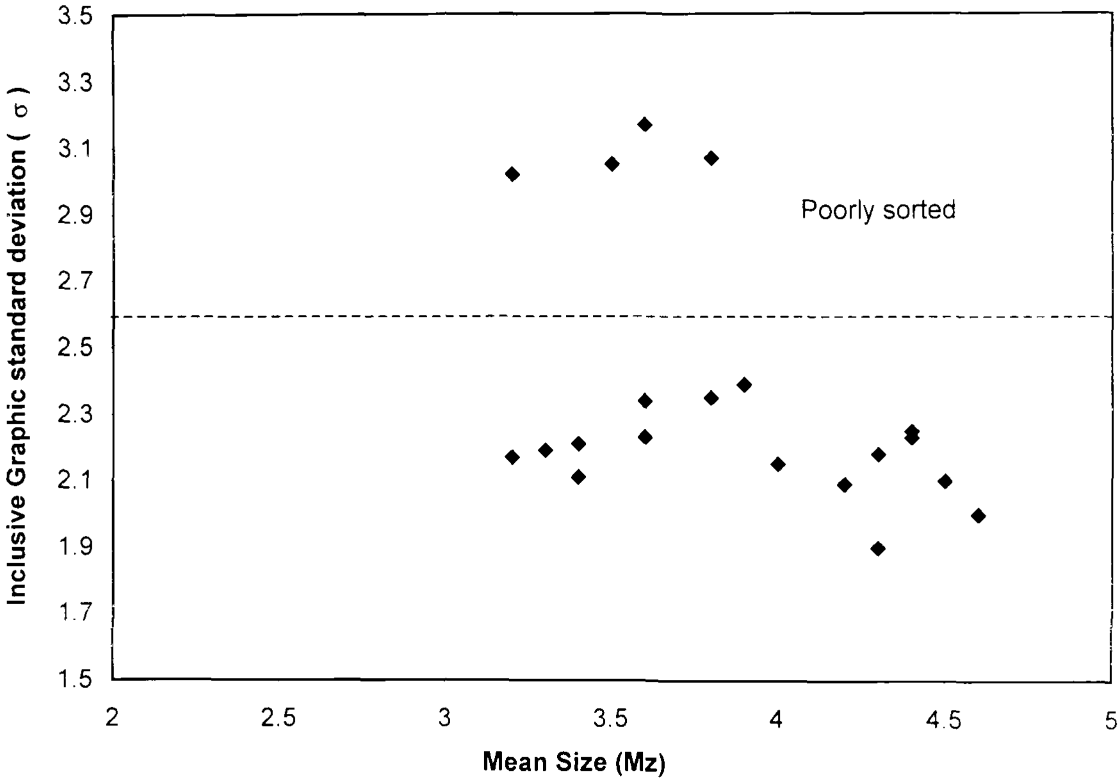


Fig.4.5b Bivariate plot of mean size versus graphicskewness

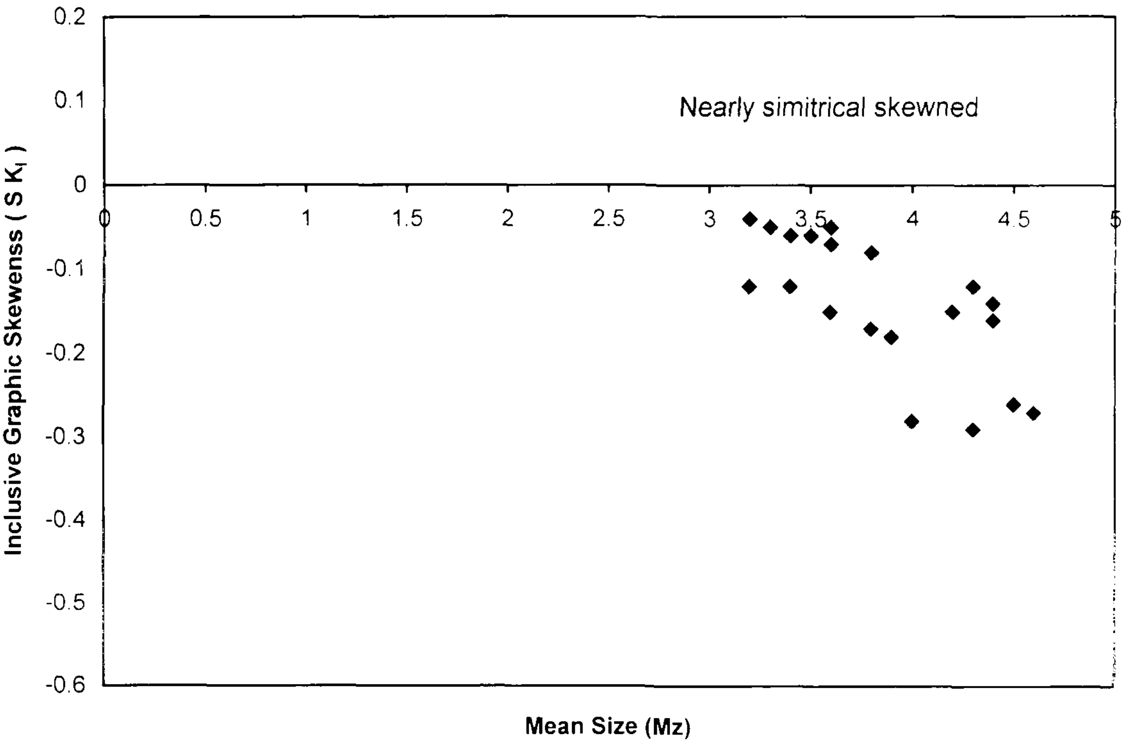


Fig.4.5c Bivariate plot of mean size versus graphic standard

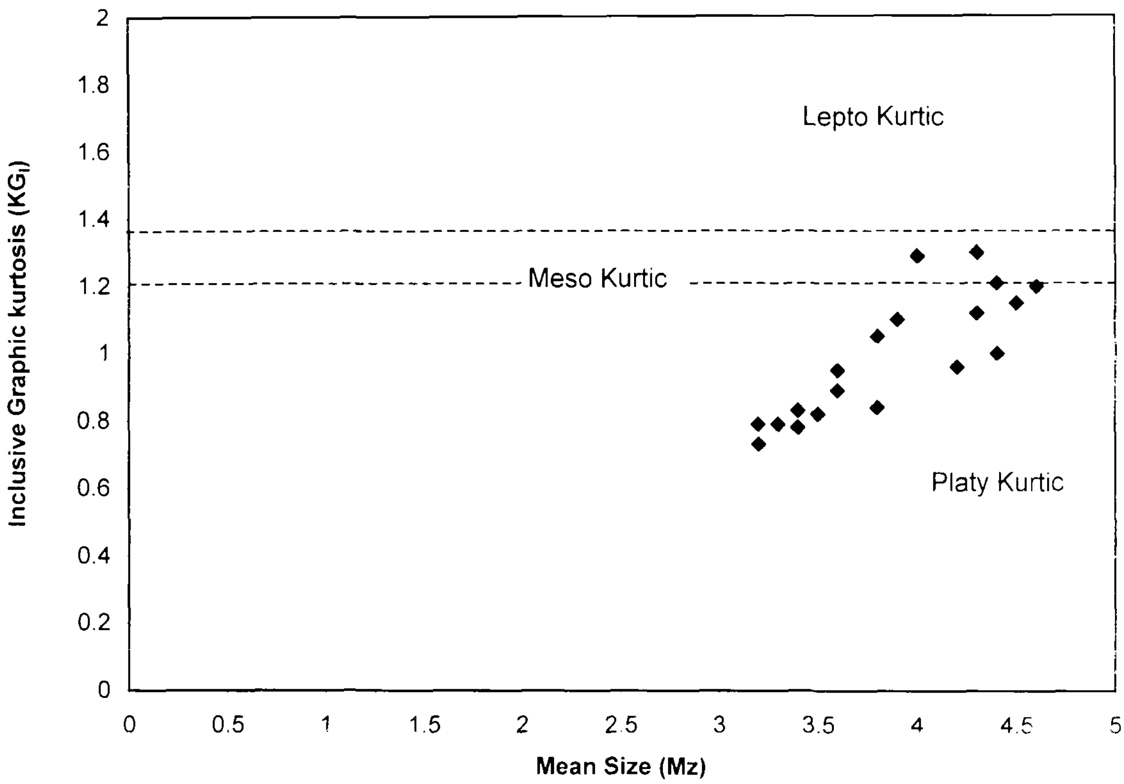


Fig.4.5d Bivariate plot of graphic skewness versus graphic standard deviation

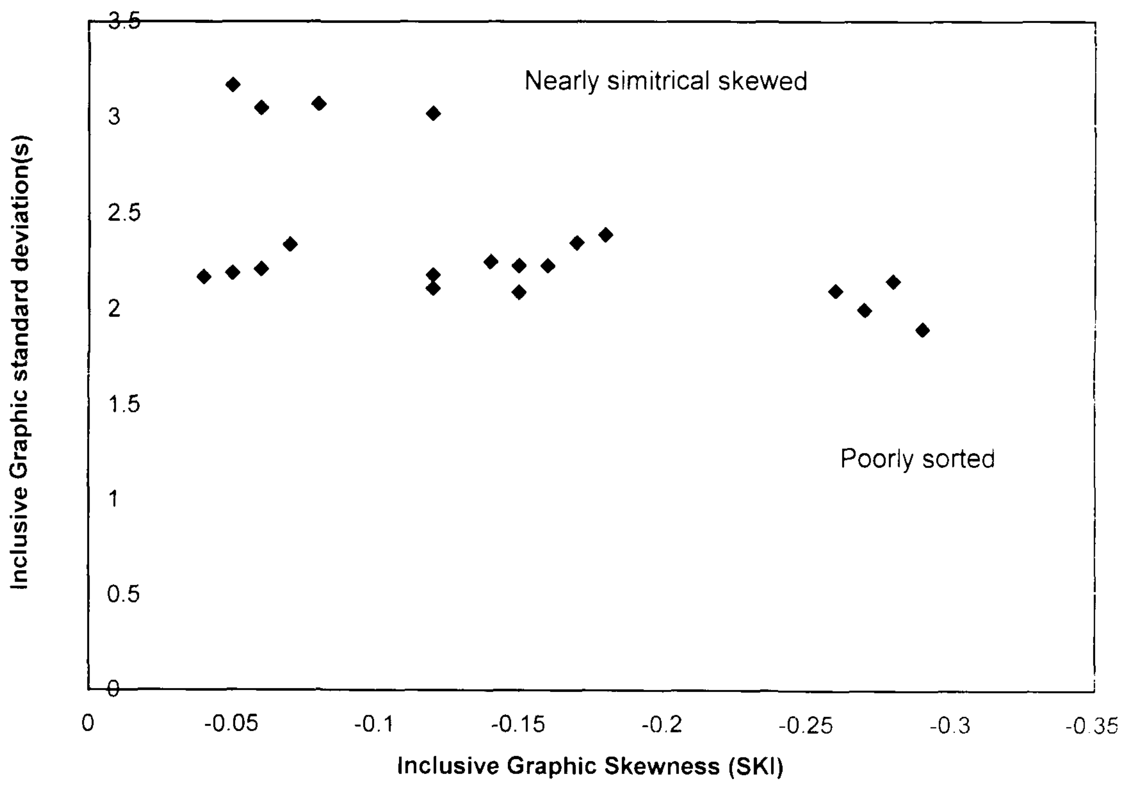


Fig.4.5e Bivariate plot of graphic skewness versus graphic kurtosis

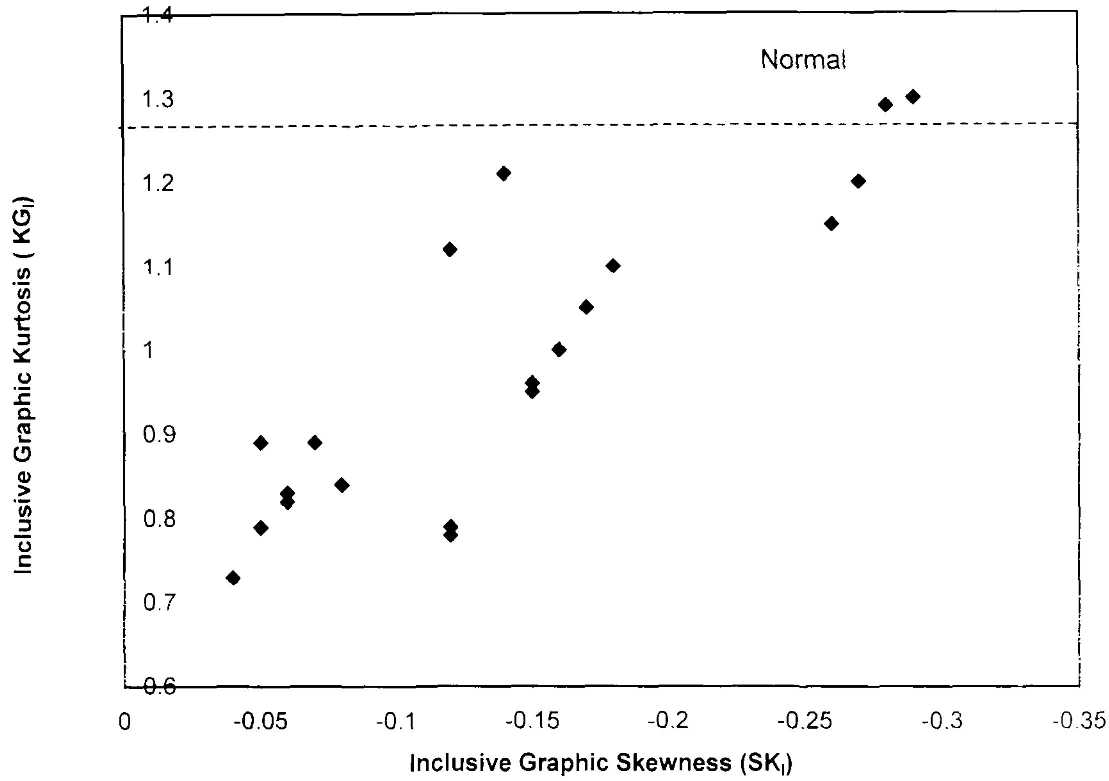
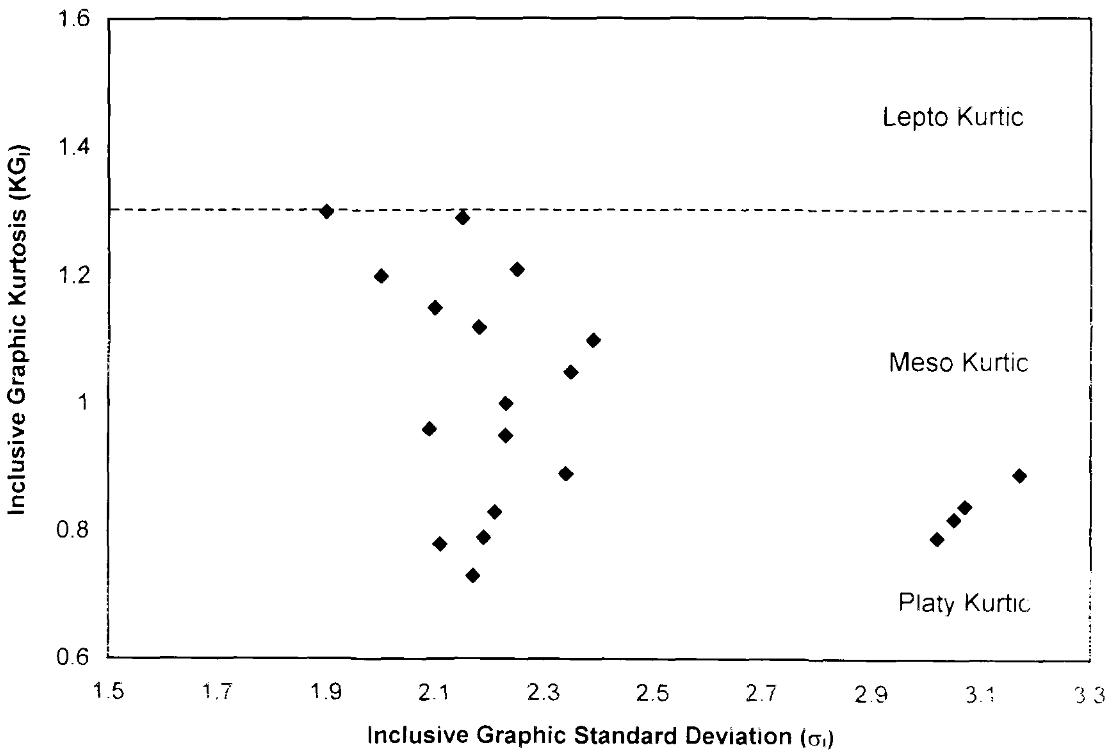


Fig.4.5f Bivariate plot of standard deviation versus graphic kurtosis



4.3 TEMPO-SPATIAL VARIATIONS OF MAJOR AND TRACE ELEMENTS IN DAL LAKE SEDIMENTS

It is a normal routine for environmental scientists to deal with a group of major and heavy metal pollutants vis Cu, Pb, Zn, Ni, Cr, Cd, and As for the pollution assessment in different environments. In this study besides various major elements an attempt has been made to analyze Cu, Pb, Zn, Ni and Co on seasonal basis and the results are summarized in Table 4.3 and 4.4.

4.3.1 Silicon

Silicon is the most abundant element in the earths crust after oxygen, with an average distribution of 285,000 mg/kg in igneous rocks. Its sources being resistant to chemical weathering it occurs in abundance in weathering residues, sandstones (359,000 mg/kg), argillaceous rocks (260,000µg/kg) and carbonate rocks (33900mg/Kg) (Horn and Adams 1966 and Hem 1970). Despite it's over abundance in nature, it is present in low concentration in natural waters but occurs in bulk quantities in lacustrine deposits. Silicon concentration in Dal Lake sediments vary widely from a low of 32003 µg/g to a high of 246775 µg/g. The inflow channel sediments recorded highest values of 150391 µg/g to 246775 µg/g and the Nagin basin recorded the lowest values of 32003 µg/g to 124415 µg/g (Table 4.3). After the inflow channel, Hazratbal recorded higher silicon concentration (84096 µg/g to 168846 µg/g) followed by Boddal (80749 µg/g to 167164 µg/g) and Gagribal (73163 µg/g to 162445 µg/g) in decreasing order (Fig. 4.6a).

Fig.4.6a.Spatial variation of silicon and aluminium in Dal Lake sediments.

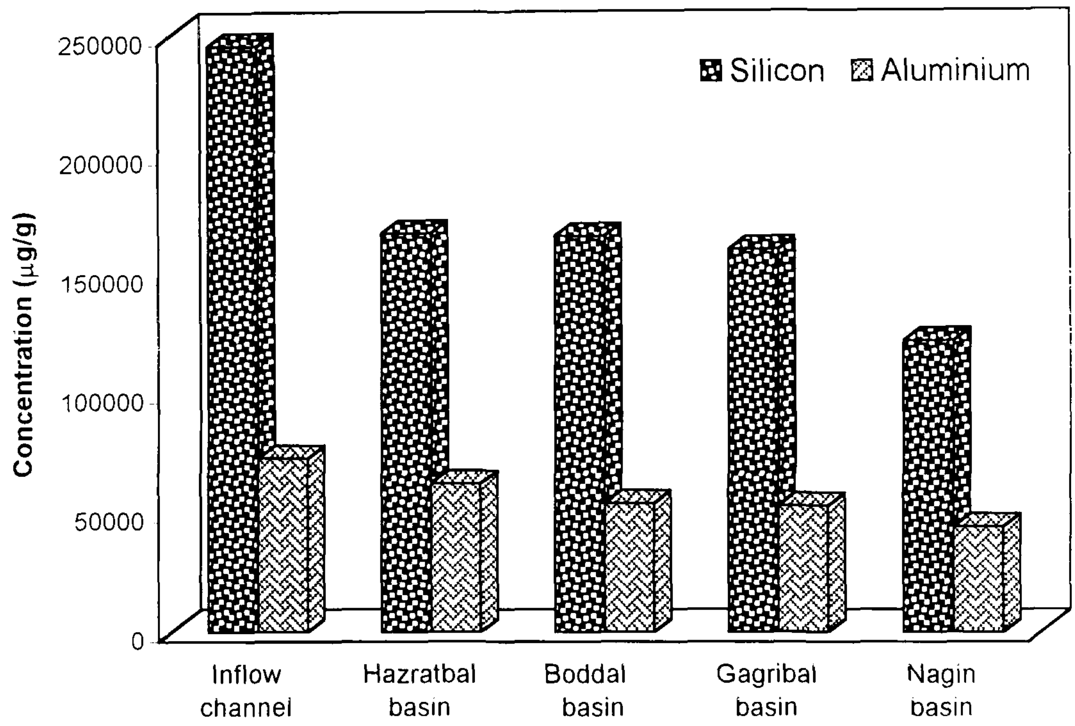
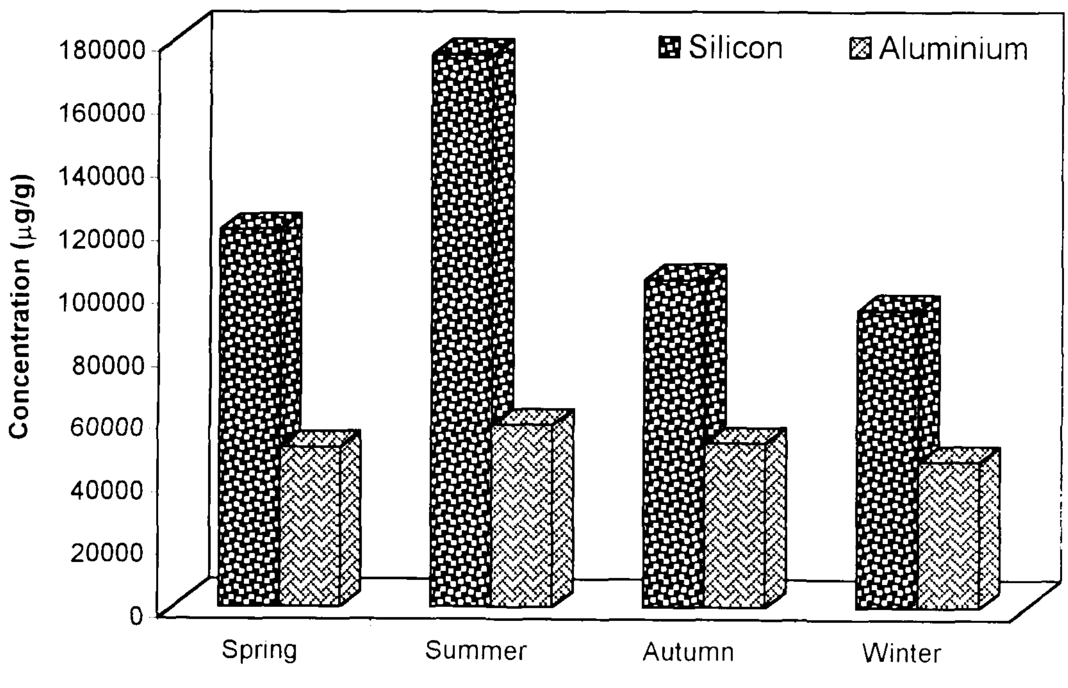


Fig.4.6b. Seasonal variations of silicon and aluminium in Dal Lake sediments.



Seasonally higher values are recorded in summer (119673 μg/g to 246775 μg/g) with average concentration of 172104 μg/g and lower values in winter (32003 μg/g to 152092 μg/g) with an average concentration of 94656 μg/g (Fig. 4.6b) whereas during spring it varies from 60249 μg/g to 166287 μg/g with an average value of 120094 μg/g and during autumn from 58460 μg/g to 216921 μg/g with an average value of 104240 μg/g respectively (Table 4.4).

4.3.2 Aluminium

Aluminium is the third most common element in igneous rocks with an average concentration of 79,500 mg/kg. In sedimentary rocks aluminium occurs as gibbsite and less often as cryolite but most of all as a component of clay minerals (Horn and Adams 1966 and Hem 1970). Its low concentration in natural waters indicates its less mobility. However, usually it occurs as second highest element in lacustrine deposits after silicon. In Dal Lake sediments aluminium concentration ranges from 31641 μg/g to 74660 μg/g (Table 4.3). Spatial distribution pattern is similar to that of silicon being highest in inflow channel (61220 μg/g to 74660 μg/g) and lowest in Nagin basin (31641 μg/g to 46404 μg/g). Hazratbal basin being close to major inflow channel recorded higher concentration (49156 μg/g to 63231 μg/g) as compared to Boddal (43765 μg/g to 56934 μg/g) and Gagribal (38679 μg/g to 54235 μg/g) basins (Table 4.3). Temporal variation reveals that throughout the whole stretch of Dal Lake higher aluminium concentration is recorded in summer and lower in winter (Fig. 4.6a). Highest values are recorded in summer (42635 μg/g to 74660 μg/g) with an average concentration of 57119 μg/g and lowest in winter (31641 μg/g to 65721 μg/g) with an average concentration of 46531 μg/g (Fig. 4.6b). Whereas spring and autumn seasons with average values of 50739 μg/g and 53146 μg/g were the intermediates between two extremes (Table 4.4).

4.3.3 Calcium

As compared to Si and Al, calcium is found in low concentration in lithosphere with an average value of 36,200 mg/kg in igneous rocks. The chief calcium containing minerals are plagioclase, feldspar, amphibole and pyroxene groups. On weathering and deposition it is retained in resistates (22,400 mg/kg) or in clayey rocks (22,500 mg/kg). Its chief concentration is found in carbonate rocks (272,000 mg/kg) (Horn and Adams 1966 and Hem 1970). In Dal Lake sediments, it shows a wide amplitude and varies from 749 μg/g to 43917 μg/g. Spatially the highest values are recorded in inflow channel, varying from 40300 μg/g to 43917 μg/g and lowest in Boddal basin varying from 749 μg/g to 2679 μg/g (Table 4.3). Hazratbal basin recorded the higher values of 1460 μg/g to 29348 μg/g as compared to Nagin (1342 μg/g to 3118 μg/g) and Gagribal (923 μg/g to 3042 μg/g) (Fig. 4.7a). Seasonal distribution pattern was quite opposite to that of Si and Al, being high in winter and low in summer at all the study sites.

Tables 4.3 Summary of spatial fluctuation of major and trace element concentration in Dal Lake sediments ($\mu g/g$).

Elements	Inflow channel (range values)	Hazratbal basin (range values)	Boddal basin (range values)	Gagribal basin (range values)	Nagin basin (range values)	Whole lake (range values)
Si	150391-246775	84096-168846	80749-167164	73163-162445	32003-124415	32003-246775
Al	61220-74660	49156-63231	43765-56934	38679-54235	31641-46404	31641-74660
Ca	40300-43917	1460-29348	749-2679	923-3042	1342-3118	749-43917
Mg	10951-12675	8910-12592	1103-9358	6925-11978	1738-10217	1103-12675
Na	1825-2819	865-2265	741-2037	1127-1973	563-1129	563-2819
K	3818-5644	2324-5643	1992-4980	1826-3420	1328-2659	1328-5644
Fe	7721-9582	6001-6914	4266-5189	5903-8463	3357-7735	3357-9582
Ti	1913-2712	2077-3623	2339-5171	2719-5792	2808-4204	1913-5792
Mn	632-893	750-968	625-867	594-903	1032-1197	594-1197
P	260-370	334-615	410-776	533-835	371-667	260-835
Zn	131-198	152-242	189-257	210-309	203-297	131-309
Cu	57-78	59-93	67-96	73-135	69-108	57-135
Co	11-18	12-22	12-23	13-27	13-24	11-27
Pb	10-22	12-26	13-28	17-32	16-31	10-32
Ni	10-18	11-20	11-20	13-23	13-21	10-23

Table 4.4 Summary of seasonal fluctuation of major and trace element concentration in Dal Lake sediments (μg/g).

Elements	Spring			Summer			Autumn			Winter		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Si	60249	166287	120094	119673	246775	122104	58460	216921	104240	32003	152092	94656
Al	34217	72451	50739	42635	74660	57119	33653	72096	53146	31641	65721	46531
Ca	1021	42322	11805	749	40937	9293	801	42925	9698	1907	43917	15923
Mg	7819	11878	9578	1103	11127	6206	8532	11823	6206	8768	12675	11029
Na	563	2242	1290	568	2701	1320	987	2819	1915	810	2389	1448
K	1328	4310	2451	1992	4135	2695	2369	5644	4297	2208	5364	3305
Fe	4298	7938	6410	3357	9017	5823	4832	9582	7371	4292	9230	6700
Ti	2373	5342	3762	2167	5792	3792	2039	3291	2675	1913	3979	2946
Mn	789	1197	927	618	1178	862	598	1105	769	594	1129	809
P	325	708	518	347	835	612	338	689	540	260	586	410
Zn	142	249	204	184	309	252	152	246	210	131	216	181
Cu	62	93	77	65	193	100	60	96	75	57	92	70
Co	12	25	19	12	27	17	12	20	14	11	18	14
Pb	12	27	21	17	32	24	11	25	19	10	25	17
Ni	12	23	18	11	22	15	10	20	15	11	20	14

Over all, calcium depicted higher values of 1907 μg/g to 43917 μg/g with an average concentration of 15923 μg/g during winter and lower values of 749 μg/g to 40937 μg/g with an average concentration of 9293 μg/g during summer (Fig. 4.7b). During spring and autumn it varies from 1021 μg/g to 42322 μg/g and 801 μg/g to 42925 μg/g with average values of 11805 μg/g and 9698 μg/g respectively (Table 4.4).

4.3.4 Magnesium

Like calcium, magnesium also occurs in low concentration with an average distribution of 17,600 mg/kg in igneous rocks. Magnesium is mainly held in olivine series, pyroxene, amphibolite, mica and chlorite groups besides in magnesium bearing clay minerals. After being released by weathering it is incorporated in resistates (8100 mg/kg), hydrolysates (16,400 mg/kg) and its major amount is contained in precipitates (45,300 mg/kg) (Horn and Adams 1966 and Hem 1970). In Dal Lake sediments its concentration ranges between 1103 μg/g and 12675 μg/g. Spatial distribution pattern is similar to that of calcium. The magnesium concentration is higher in inflow channel sediments (10951 μg/g to12675 μg/g) and lesser in Boddal basin (1103 μg/g to 9358 μg/g) (Table 4.3). Magnesium concentration in Hazratbal basin is relatively higher and ranges between 8910 μg/g and 12592 μg/g, whereas Gagribal and Nagin basins show magnesium concentration of 6925 μg/g to 11978 μg/g and 1738 μg/g to 10217 μg/g respectively (Fig. 4.7a).

Fig.4.7a. Spatial variation of calcium and magnesium in Dal Lake sediments.

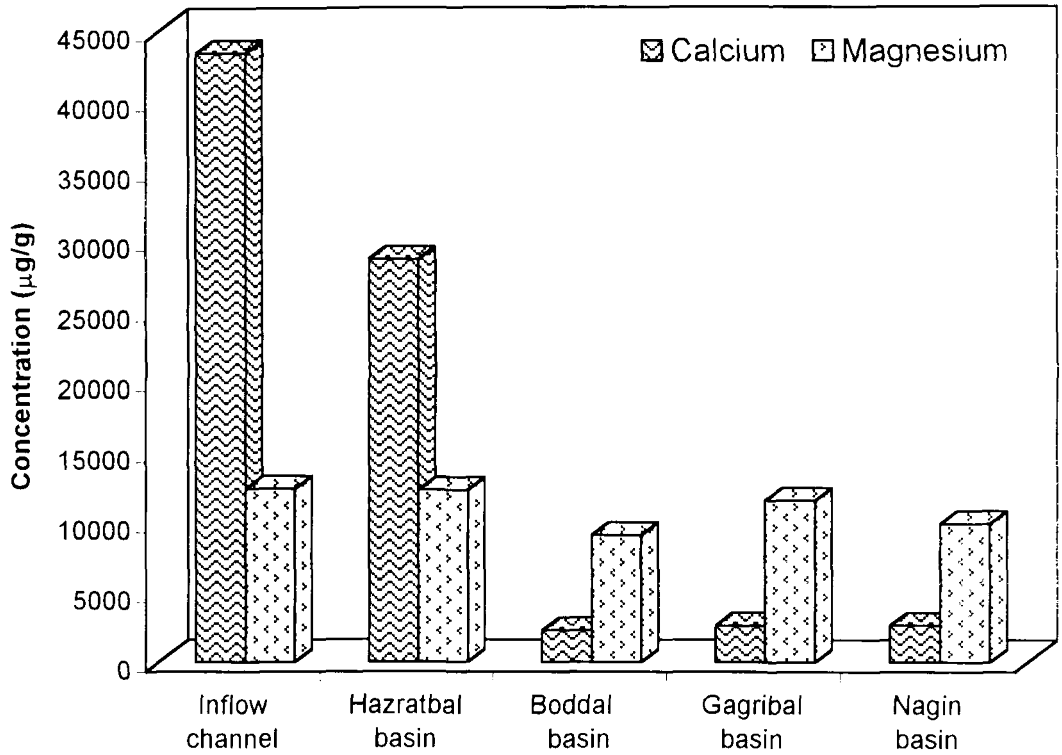
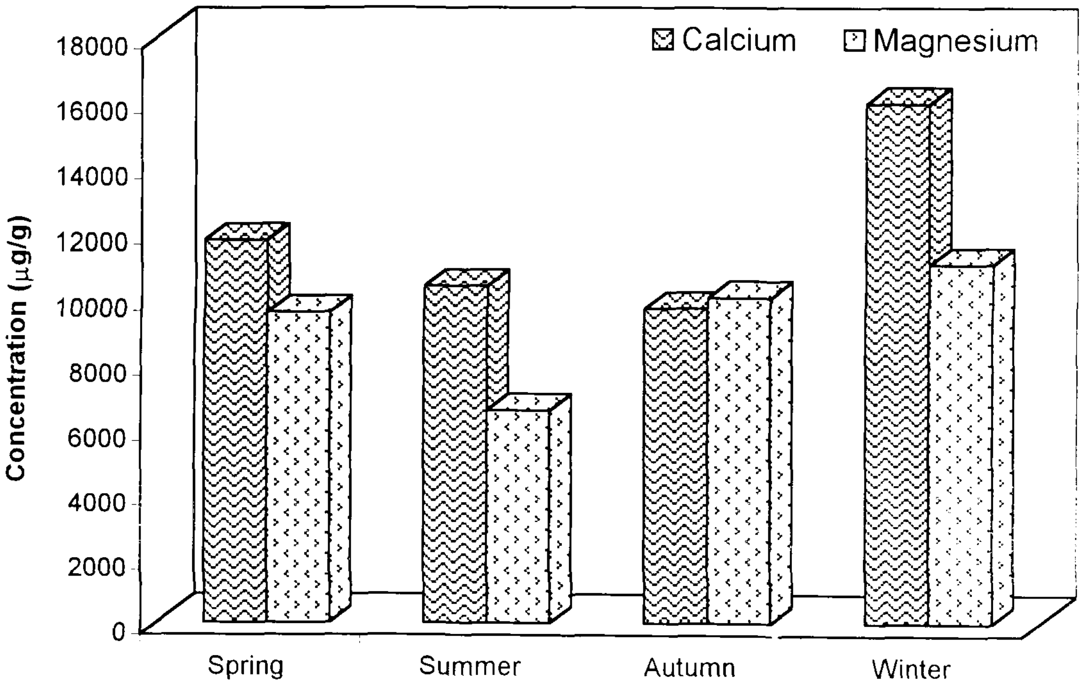


Fig.4.7b. Seasonal variation of calcium and magnesium in Dal Lake sediments.



The seasonal distributional pattern of magnesium like calcium depicted higher concentration during winter and lower during summer. Throughout the whole lake area higher values (8767 μg/g to 12675 μg/g) are recorded in winter and lower (1103 μg/g to 11127 μg/g) in summer. Intermediate values of 7819 μg /g to 11878 μg /g and 8532 μg /g to 1823 μg /g are recorded in spring and autumn respectively (Table 4.4). The highest average concentration (11029 μg/g) is observed during winter followed by spring (9578 μg /g) where as summer and autumn have same average value of 6206 μg /g (Fig. 4.7b).

4.3.5 Sodium

Generally sodium occurs in low concentration than calcium and magnesium with an average concentration of 28,100 mg/kg. It is the major constituent of igneous rocks and is mainly held in plagioclase, soda lime feldspar, zeolite group and sodium containing silicates. Its distribution and liberation depends on the weathering of these silicates. In sandstones and clayey rocks, its average concentration is 3870 mg/kg and 4850 mg/kg respectively (Horn and Adams 1966 and Hem 1970). However, in Dal Lake sediments its concentration ranges between 563 μg/g and 2819 μg/g. Maximum value of 825 μg/g to 2819 μg/g are recorded in inflow channel and minimum values of 563 μg/g to 1129 μg/g in Nagin basin (Table 4.3). Comparatively higher concentration is recorded in Hazratbal, varying between 865 μg/g and 2265 μg/g and Boddal recorded the intermediate values of 741 μg/g to 2037 μg/g (Fig. 4.8a).

Fig.4.8a. Spatial variation of sodium and potassium in Dal Lake sediments.

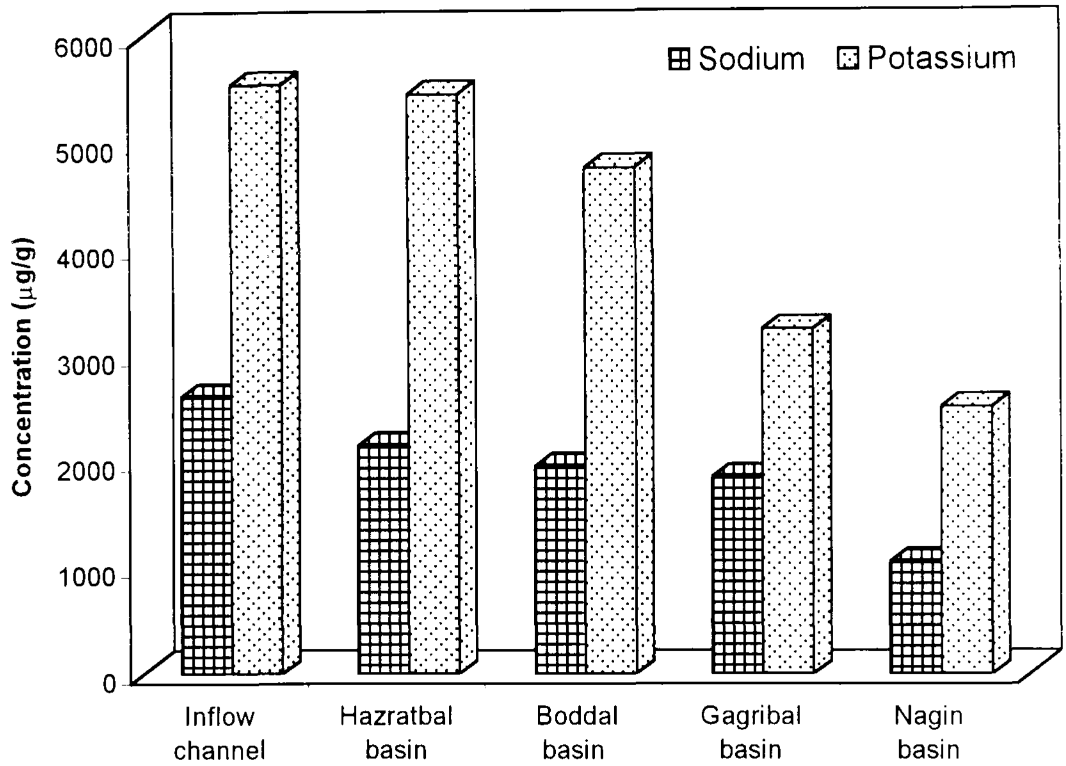
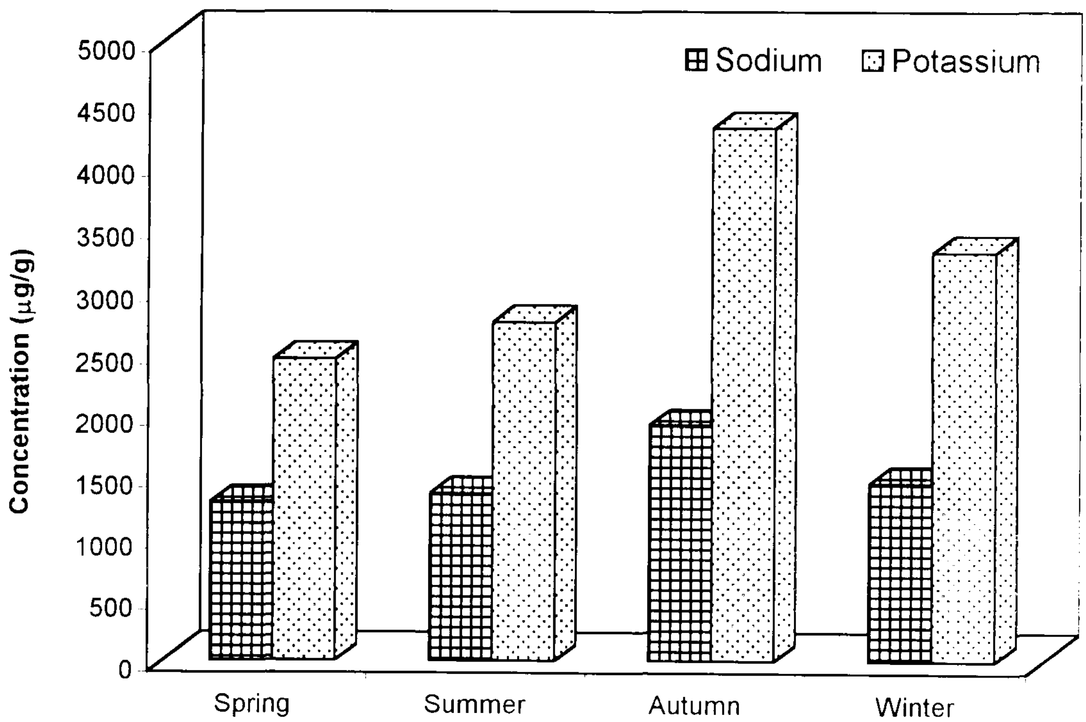


Fig.4.8b. Seasonal variation of sodium and potassium in Dal Lake sediments.



Seasonal variation shows that low values (563 μg/g to 2242 μg/g) are recorded in spring which gradually rose in summer (568 μg/g to 2701 μg/g) and peaked in autumn (987 μg/g to 2819 μg/g) and then onwards decreases in winter (810 μg/g to 2389 μg/g) (Table 4.4). The highest average concentration (1915 μg/g) is recorded in autumn and lowest (1290 μg/g) in spring, whereas summer and winter reveal intermediate values of 1320 μg/g and 1448 μg/g respectively (Fig. 4.8b).

4.3.6 Potassium

Potassium is an important constituent of igneous rocks with an average concentration of 25,700 mg/kg, occurs mainly in the potassium feldspar, orthoclase and microcline, besides in the muscovite, micas, biotite, leucite and nepheline. Inspite of its low geochemical mobility, potassium ions are released by weathering but after more or less prolonged migration they tend to become fixed again on clay minerals as is evident by its abundance in clays (24,900 mg/kg) (Horn and Adams 1966 and Hem 1970). In Dal Lake sediments, potassium concentration ranges from 1328 μg/g to 5644 μg/g. Among various study sites, inflow channel sediments recorded highest potassium values varying from 3818 μg/g to 5644 μg/g and Nagin recorded lowest values of 1328 μg/g to 2659 μg/g whereas Hazratbal shows higher concentration (2324 μg/g to 5643 μg/g) as compared to Boddal (1992 μg/g to 4980 μg/g) and Gagribal (1826 μg/g to 3420 μg/g) (Table 4.3). Temporally higher values of potassium are recorded in autumn (2369 μg/g to 5644 μg/g) with an average value of 4297 μg/g (Fig. 4.8a). Lower values are recorded in spring (1328 μg/g to 4310 μg/g) and summer (1992 μg/g to 4135 μg/g) with average values of 2451 μg/g and 2695 μg/g respectively (Fig. 4.8b). Potassium concentration in winter varies from 2208 μg/g to 5364 μg/g with an average value of 3305 μg/g (Table 4.4).

4.3.7 Iron

Iron, with an average concentration of 42,200 mg/kg in igneous rocks, occurs mainly in the dark colored minerals like pyroxenes, amphiboles, garnet and olivine. It is found in abundance in the argillaceous rocks (38,000 mg/kg) and sand stones (18,600 mg/kg) but in lower concentration in carbonate rocks (8190 mg/kg) (Horn and Adams 1966 and Hem 1970). In sediments, it occurs as trivalent iron in oxides and hydroxides. Iron concentration in Dal Lake sediment samples ranges between 3357 μg/g and 9582 μg/g (Table 4.3). Site variation shows that the inflow channel recorded higher concentration (7721 μg/g to 9582 μg/g) followed by Gagribal (5903 μg/g to 8463 μg/g), Hazratbal (6001 μg/g to 6914 μg/g) and Boddal (4266 μg/g to 5189 μg/g) in a decreasing order. Iron shows wide variation in Nagin basin varying from 3317 μg/g to 7735 μg/g (Fig. 4.9a). In Lake Sediments high iron values were observed during autumn (4832 μg/g to 9582 μg/g) and low during summer (3357 μg/g to 9017 μg/g).

Fig.4.9a. Spatial variation of iron and titanium in Dal Lake sediments.

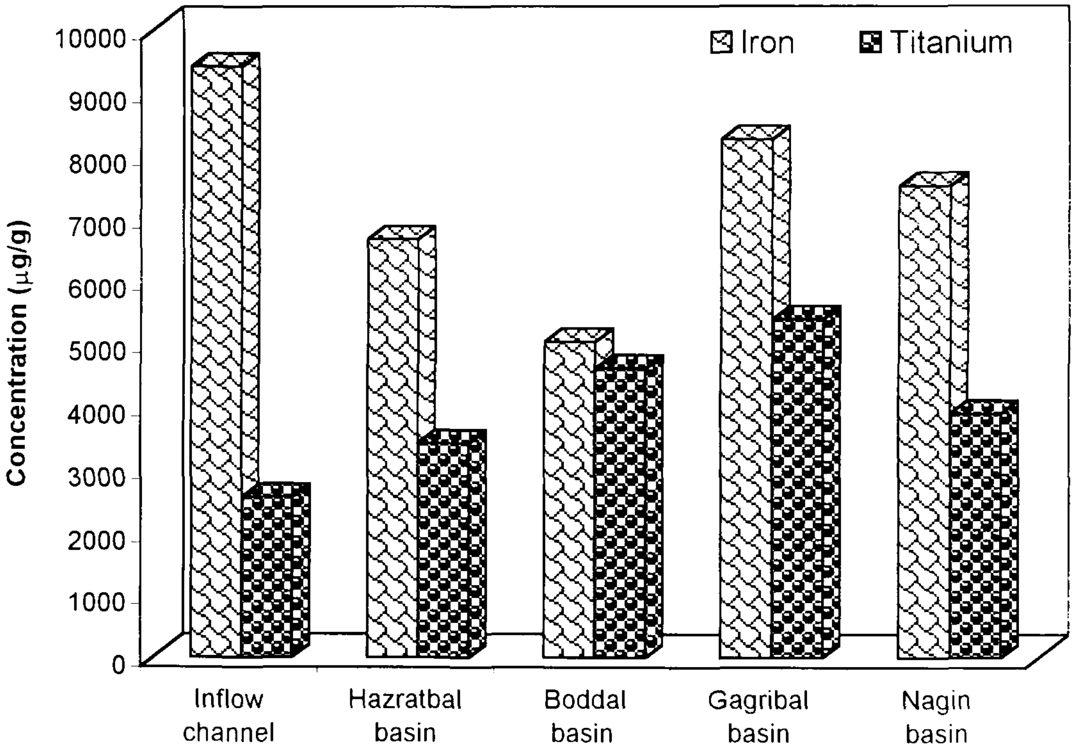
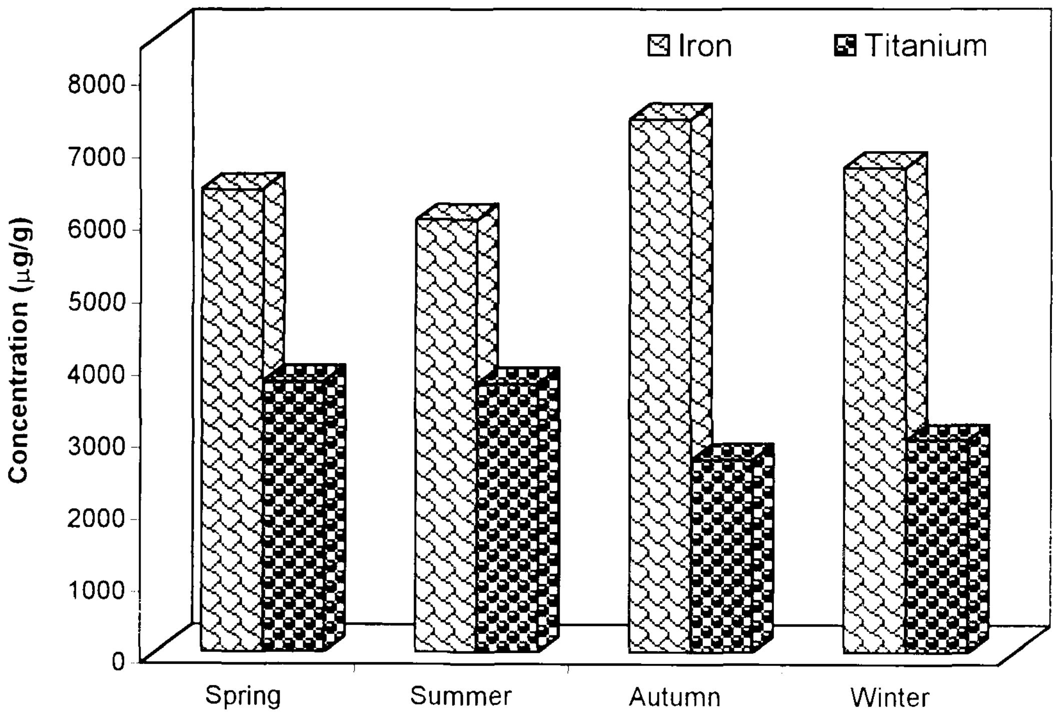


Fig.4.9b. Seasonal variation of iron and titanium in Dal Lake sediments.



However in spring and winter almost similar values were recorded which vary from 4298 μg/g to 7938 μg/g and 4292 μg/g to 9230 μg/g respectively (Table 4.4). Highest average Iron concentration was observed in autumn (7371 μg/g) and lowest in summer (5823 μg/g) (Fig. 4.9b).

4.3.8 Titanium

Titanium like other major elements is found in higher concentration in lithosphere, in Dal Lake sediments ranges from 1913 μg/g to 5792 μg/g (Table 4.3). A comparison of various study sites reveals that the highest concentration was recorded in Gagribal varying from 2719 μg/g to 5792 μg/g and the lowest in inflow channel varying from 1913 μg/g to 2721 μg/g. Higher concentration was recorded in Boddal (2339 μg/g to 5171 μg/g, as compared to Nagin (2808 μg/g to 4204 μg/g) and Hazratbal (2077 μg/g to 3623 μg/g) (Fig. 4.9a). Seasonal variations in the titanium concentration shows a quite opposite trend in its distribution pattern with higher concentrations in spring (2373 μg/g to 5342 μg/g) and summer (2167 μg/g to5792 μg/g) and lower in autumn (2039 μg/g to 3291μg/g) and winter (1913 μg/g to 3979 μg/g) respectively (Table 4.4). The highest average concentration (3792 μg/g) was observed during summer and lowest (2675 μg/g) during autumn while spring with 3762 μg/g and winter with 2946 μg/g were the intermediates between two extremes (Fig. 4.9b).

Mathess. G, Frimmel, F.H, Hirsch. P, Schulz, H.D.
Usdowski, E, (Eds) (1992)

4.3.9 Manganese

Manganese is one of the miner constituents of igneous rocks with an average concentration of 937 mg/kg. Its low geochemical mobility is reflected by its lower concentration in clay (575 mg/kg), sandstones (392 mg/kg) and precipitates (842 mg/kg) (Horn and Adams 1966 and Hem 1970). In Igneous rocks it occurs in ferromagnesian minerals like biotite and hornblende and is widely distributed in sediments and soils as oxides and hydroxides. In the Dal Lake area manganese concentration in sediment samples ranges from 594 μg/g to1197 μg/g. μg/g. The Nagin basin sediment recorded high manganese concentration (1032 μg/g to 1197 μg/g) in comparison to Gagribal basin (594 μg/g to 903 μg/g) (Table 4.3). Hazratbal recorded comparatively higher values (750 μg/g to 968 μg/g) than inflow channel (632 μg/g to 893 μg/g) and Boddal (625 μg/g to 867 μg/g) (Fig. 4.10a). Seasonality of manganese concentration reveals a definite seasonal trend in its distributional pattern, with almost all the study sites recorded higher concentration during spring and lower in autumn, except Gagribal basin which recorded high concentration in summer and low in winter. Overall higher manganese concentration (789 μg/g to 1197 μg/g) with an average value of 927 μg/g was recorded in spring and lower concentration of 598 μg/g to1105 μg/g with an average value of 769 μg/g in autumn (Fig. 4.10b). Manganese concentration during summer vary between 618 μg/g and 1178 μg/g during winter between 594 μg/g and 1129 μg/g with average values of 862 μg/g and 809 μg/g respectively (Table 4.4).

4.3.10 Phosphorus

With an average concentration of 1100 mg/kg, phosphorous is one of the important elements of igneous rocks in which it chiefly occurs as appetite mineral. It is found in low concentration in clayey rocks (733 mg/kg), sandstones (539 mg/kg) and carbonate rocks (281 mg/kg) (Horn and Adams 1966 and Hem 1970). Most of the phosphorous liberated after weathering is adsorbed on clay minerals. The annual amplitude of phosphorus in sediment samples of Dal Lake ranges from 260 μg/g to 835 μg/g. Spatial distribution pattern shows highest concentration in Gagribal (533 μg/g to 835 μg/g) and the lowest in inflow channel (260 μg/g to 370 μg/g) (Table 4.3). The Boddal also showed higher concentration of 410 μg/g to 776 μg/g as compared to Nagin (371 μg/g to 667 μg/g) and Hazratbal (334 μg/g to 615 μg/g) (Fig. 4.10a). In general all the study sites recorded higher concentration during summer and lower during winter. Highest phosphorous concentration being recorded during summer (347 μg/g to 835 μg/g) with an average value of 612 μg/g and the lowest in winter (260 μg/g to586 μg/g) with an average value of 410 μg/g (Table 4.4), whereas spring and autumn with average values of 518 μg/g and 540 μg/g posses intermediate position (Fig. 4.10b).

Fig.4.10a. Spatial variation of manganese and phosphorus in Dal Lake sediments.

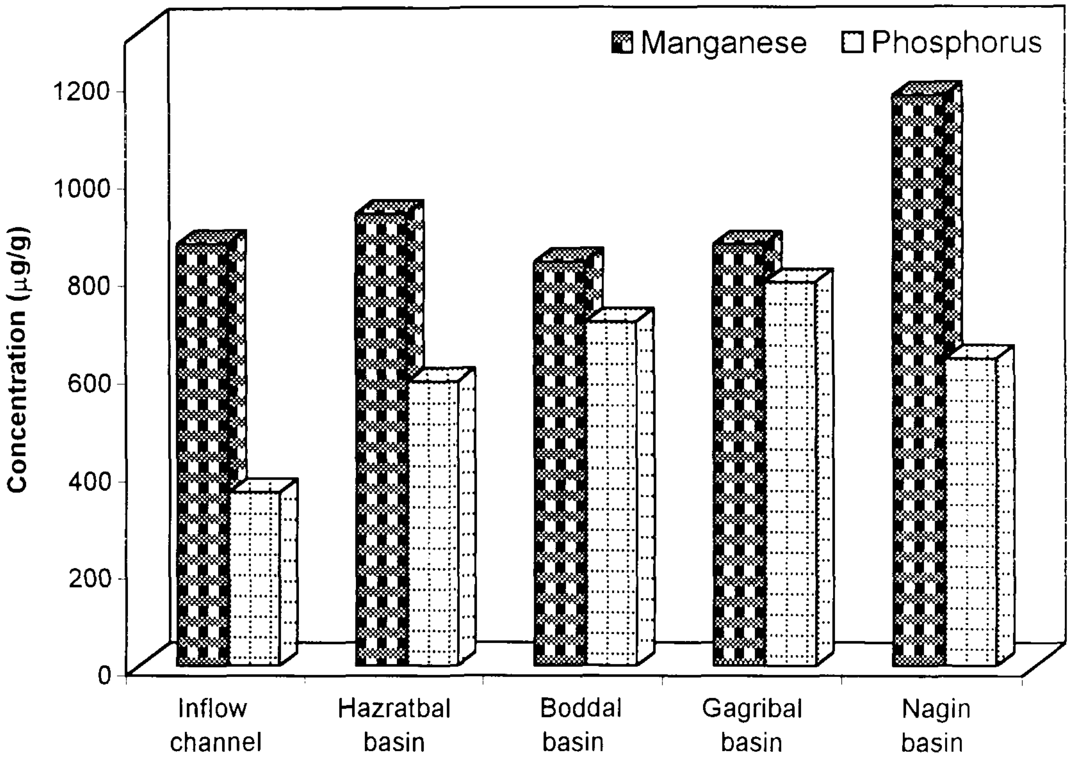
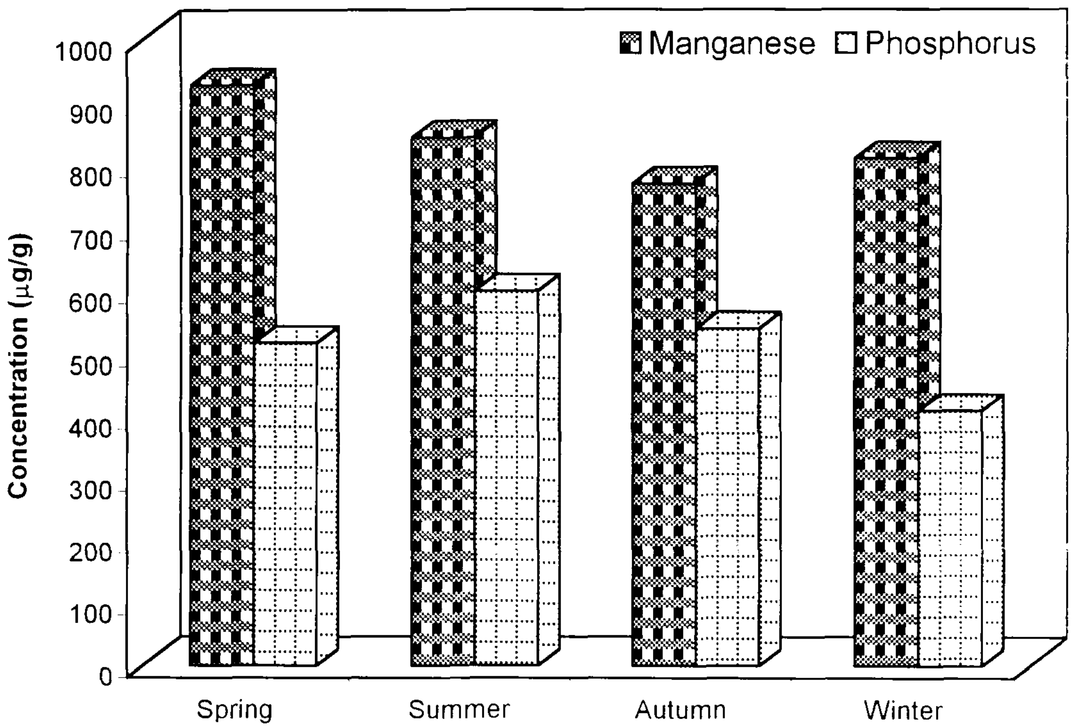


Fig.4.10b. Seasonal variation of manganese and phosphorus in Dal Lake sediments.



4.3.11 Zinc

Zinc being a trace element occurs in igneous rocks with an average concentration of 80mg/kg. Its concentration is very low in sandstones (16.3mg/kg) and carbonate rocks (15.6mg/kg). However, in clayey rocks its concentration is relatively high (130mg/kg) (Horn and Adams 1966 and Hem 1970). This universally used heavy element is commonly found in the vicinity of metallurgical works, wastes and mine tailings. In the study area zinc concentration in lake sediments depicted a wide range, varied between 131 μg/g and 309 μg/g (Table 4.3). Spatial distribution of zinc shows that Gagribal basin recorded higher concentration (210 μg/g to 309 μg/g) followed by Nagin (203 μg/g to 297 μg/g), Boddal (189 μg/g to 257 μg/g), Hazratbal (152 μg/g to 242 μg/g) and inflow channel (131 μg/g to 198 μg/g) in a decreasing order (Fig. 4.11a). Seasonally higher values (184 μg/g to 309 μg/g) are recorded in summer and lower (131 μg/g to 216 μg/g) in winter (Table 4.4). Similarly highest average zinc concentration is recorded in summer (252 μg/g) and lowest in winter (181 μg/g). Spring and autumn recorded intermediate average values of 204 μg/g and 210 μg/g respectively (Fig. 4.11b).

4.3.12 Copper

Copper is one of the common heavy elements in lithosphere, with average concentration of 97.4 mg/kg in igneous rocks, 44.7 mg/kg in clay and 15.4 mg/kg and 4.44 mg/kg in sandstone and carbonates respectively, (Horn and Adams 1966 and Hem 1970).

Fig.4.11a. Spatial variation of zinc and copper in Dal Lake sediments.

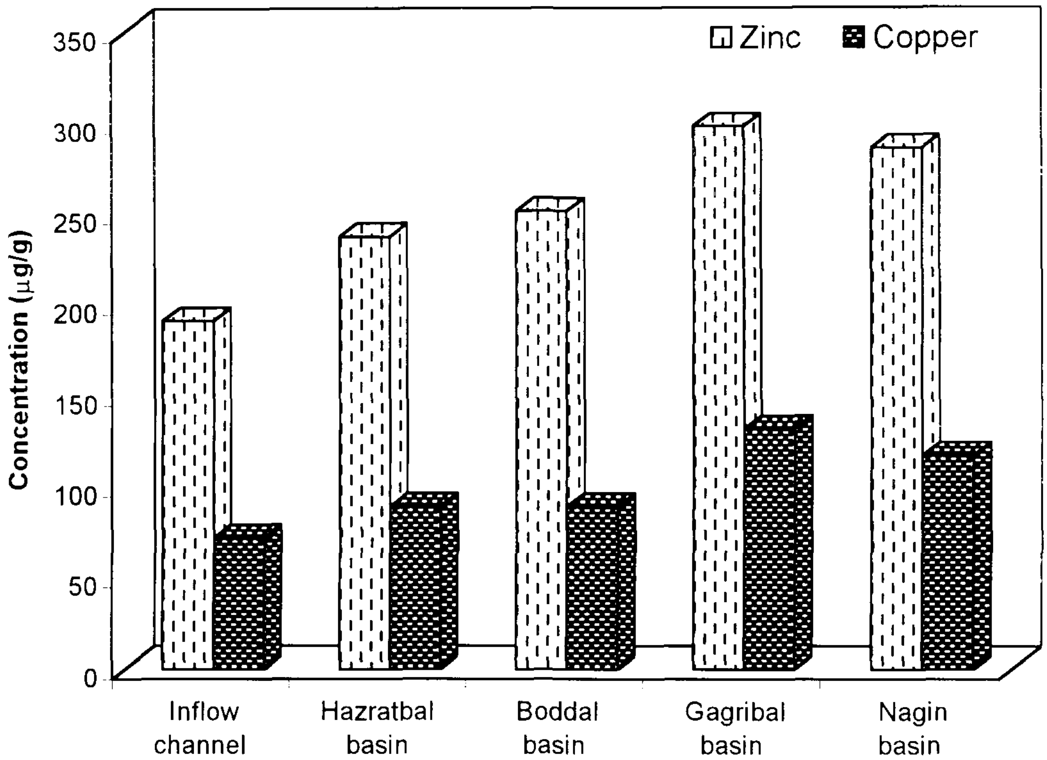
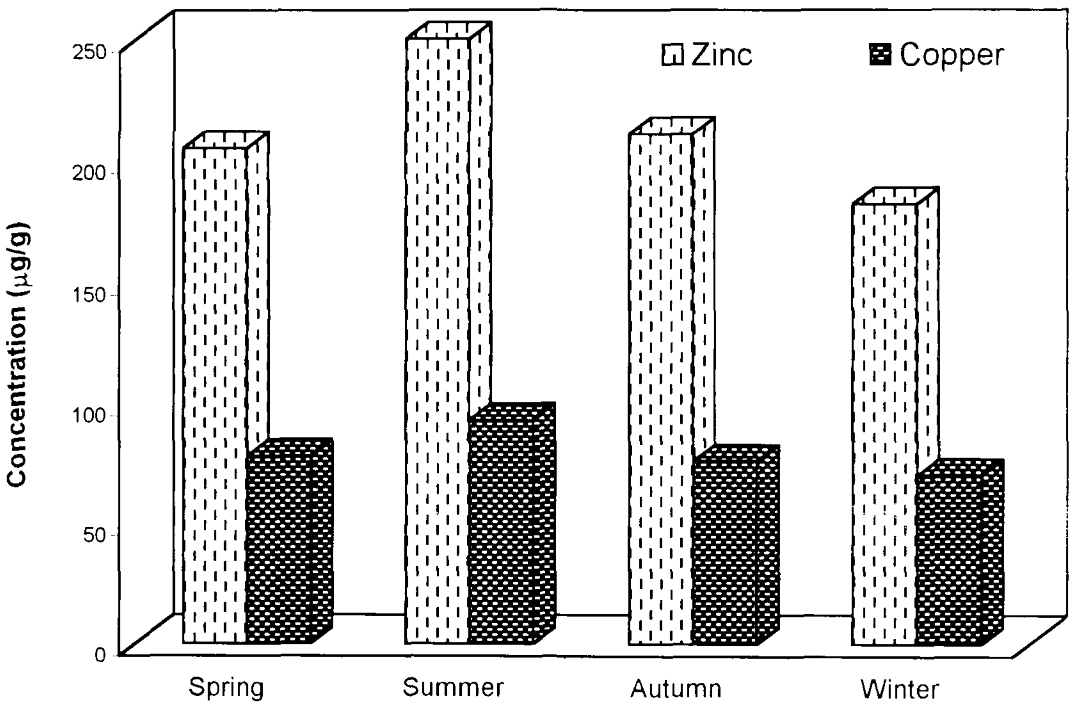


Fig.4.11b. Seasonal variation of zinc and copper in Dal Lake sediments.



It is mainly held in sulfides, oxides and hydroxy-carbonates. In Dal Lake sediments, copper shows the next higher concentration after zinc and varies between 57 μg/g to 135 μg/g (Table 4.3). Maximum values ranging from 73 μg/g to 135 μg/g are recorded in Gagribal basin and minimum values (57μg/g to 78 μg/g) in inflow channel sediments (Fig. 4.11a). Nagin basin being influenced by Gagribal also recorded comparatively higher concentration (69 μg/g to 108 μg/g) than Boddal (67 μg/g to 96 kg/g) and Hazratbal (59 μg/g to 93 μg/g). Though copper does not show marked seasonal variation but it recorded higher concentration (65 μg/g to 193 μg/g) in summer with an average value of 100 μg/g and comparatively lower concentration (57 μg/g to 92 μg/g) in winter with an average value of 70 μg/g (Fig. 4.11b).

4.3.13 Cobalt

Cobalt, with an average distribution of 23 mg/kg in igneous rocks is mostly found in ultrabasic rocks. Traces of it are found in resistates (0.328 mg/kg) and carbonate rocks (0.123 mg/kg). However, clayey rocks have comparatively higher concentration (8.06 mg/kg) (Horn and Adams 1966 and Hem 1970). In Dal Lake sediments Cobalt concentration varies from11 μg/g to 27 μg/g (Table 4.3). Spatial and temporal variation does not show any definite distributional pattern. Higher values are recorded at Gagribal and Nagin (13 μg/g to 27μg/g) and lower in Hazratbal and Boddal (12 μg/g to 23 μg/g), where as inflow channel recorded the least concentration (11 μg/g to 18 μg/g) (Fig. 4.12a).

Fig.4.12a. Spatial variation of cobalt, lead and nickel in Dal Lake sediments.

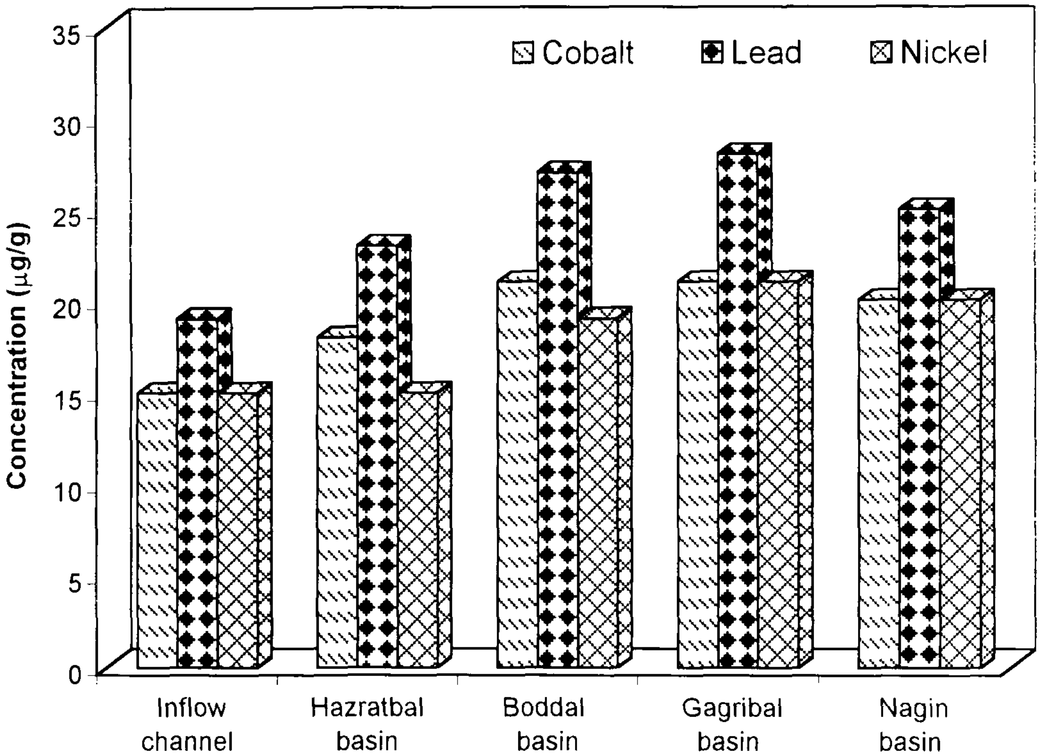
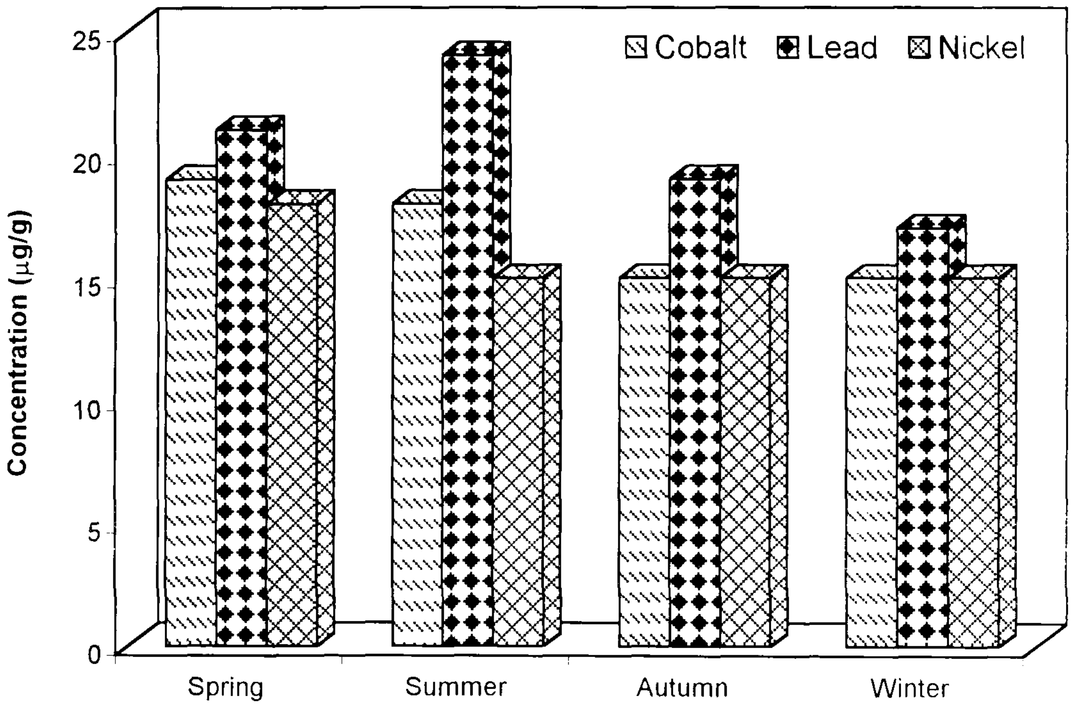


Fig.4.12b. Seasonal variation of cobalt, lead and nickel in Dal Lake sediments.



Seasonally, no marked difference was noticed and recorded almost similar values in summer (12 µg/g to 27 µg/g), spring (12 µg/g to 25 µg/g), autumn (12 µg/g to 20 µg/g) and winter (11 µg/g to 18 µg/g) (Table 4.4). Maximum average concentration is recorded in spring (19 µg/g) and minimum in winter (14 µg/g) whereas summer with 18 µg/g and autumn with 15 µg/g recorded the intermediate values (Fig. 4.12b).

4.3.14 Lead

Lead is distributed in low concentration in lithosphere with an average concentration of 15.6 µg/g in igneous rocks and 13.5 mg/kg in sand stones and carbonate rocks respectively, but in clayey rocks it is enriched (80 mg/kg) Horn & Adam 1966 and Hem 1970. In Dal Lake sediments lead concentration ranges betwee10 µg/g to 32 µg/g. Highest concentration being observed in Gagribal (17 µg/g to 32 µg/g) and lowest in inflow channel (10 µg/g to 22 µg/g) (Table 4.3). However, Nagin Boddal and Hazratbal basins do not show any marked difference and it ranges from 16 µg/g to 31 µg/g, 13 µg/g to 28 µg/g and 12 µg/g to 26 µg/g respectively (Fig. 4.12a). Similarly seasonal distribution pattern does not show much fluctuation as recorded higher values during summer ranges between 17 µg/g and 32 µg/g with average concentration of 24 µg/g and lower values during winter ranging between 10 µg/g and 25 µg/g with average concentration of 17 µg/g. spring (12 µg/g to 27 µg/g) and autumn (11 µg/g to 25 µg/g) recorded intermediate values (Fig. 4.12b).

4.3.15 Nickel

It is relatively common element with an average concentration of 93.8 μg/kg, 29.4 mg/kg and 12.8 mg/kg in igneous, argillaceous and carbonate rocks respectively (Horn and Adams, 1966 and Hem, 1970). However, traces of it are found in sandstone (2.57 mg/kg). Nickel in Dal Lake sediments show little variation from 10 μg/g to 23 μg/g (Table 4.3). At both Gagribal and Nagin it ranges between 13 μg/g and 23 μg/g, while on the other side Hazratbal and Boddal basins recorded almost similar values of 11 μg/g to 20 μg/g and the lowest values (10 μg/g to 18 μg/g) are recorded in inflow channel sediments (Fig. 4.12a). Nickel also show irregular seasonal pattern, recording higher values 12 μg/g to 23 μg/g and 11 μg/g to 22 μg/g in spring and summer and lower values of 10 μg/g to 20 μg/g and 11 μg/g to 20 μg/g in autumn and winter respectively. Highest average concentration (18 μg/g) is recorded in spring (Fig. 4.12b).

* The varied concentrations are due to anthropogenic activities. The main environmental impact are the detoriation of water quality, degradation of biological life and shrinkage of lake.
* The remedial measures of the environmental impact of various elements on the Dal Lake which have already mentioned in Chapter VI are as follows:

- Solid waste management
- Houseboat sanitation
- Improvement in regional sanitation and Drainage system
- Marginal dredging, selective de-weeding
- Improvement of navigation routes.

Chapter-5
Water Quality Assessment

WATER QUALITY ASSESSMENT

Surface water or ground water originates from the pouring and / or infiltration of atmospheric precipitation. Ground water after flouring underground for varying distances feeds the surface water systems. rivers and lakes and only a small portion flows directly into the sea or evaporates. During the movement, water (whether underground water or surface water) is subjected to numerous interactions between the aqueous and the solid phases through physical, chemical and microbial processes such as dissolution, precipitation, oxidation and reduction, complexation, ad-and desorption, filtrations, gas exchange, evaporation, biological metabolism, isotopic redistribution and anthropogenic influences, which changes its typical properties (Matthess, 1982). As the water proceeds along its path, it attains its composition due to interactions with rock/soil and biota. Thus, the geochemical changes inherited by water depends on the hydrological boundaries and the hydrodynamics of the catchment area and its water budget. The concentration of the chemical constituents depends on the availability of the parent material (mineral) for a particular constituent and its dissolving capacity. Besides, the physical parameters viz, Temperature, pH, EC, DO, TDS, the chemical constituents studied in the present work are Ca, Mg, Na, K, Cl, HCO_3, NO_3, Mn. Fe, Zn and Pb.

5.1 METHODOLOGY

5.1.1 Sample collection

The objective of sampling is to collect a portion of material small enough in volume to be transported conveniently and handled in the laboratory while still accurately representing the material being sampled (APHA,1998). Samples however, have to be handled in such a way that no significant change in composition occurs before the tests are made.

Sixty water samples were collected seasonally (Fig. 4.1) between 10:00 hr and 15:00 hr from four basins of Dal Lake in one litre polyethylene bottles. Before collection the containers were washed with concentrated HNO_3 which was then completely removed with distilled water and then these bottles were, two to three times, rinsed by the water that was to be sampled. Some of the parameters including water temperature, pH, dissolved oxygen and conductivity measurements were done at the sampling sites whereas the other chemical parameters were determined within 24 hr at the Centre of Research For Development (CORD) and in department of University Scientific and Instrumentation Centre (USIC), University of Kashmir, Srinagar.

5.1.2 Analytical techniques

The water analysis was carried out according to the standard methods (Mackreth, 1963; Golterman and Clymo, 1969; APHA, 1998). Water temperature was determined by portable digital thermotron and pH was measured with the help of digital pH meter. The pH meter was standardized before use with buffer solution having pH values of 9.2 and 4.0. Dissolved oxygen and conductivity of lake water were also determined with the help of portable digital oxygen meter and conductivity meter; both the instruments were standardized before use with standard sodium sulphite (5%) and potassium chloride (0.01M) solutions respectively.

The concentration of Ca^{++}, Mg^{++}, Cl^- and HCO_3^- were determined by volumetric methods. The estimation of Ca^{++} and Mg^{++} was done by EDTA titration using Eichrome black T and murexide as indicators, whereas in Cl^- estimation water samples were titrated against $AgNO_3$ using potassium chromate as an indicator and for HCO_3^- titration was done against H_2SO_4 and methyl orange was used as an indicator. Na^+ and K^+ concentration was determined by means of flame emission photometry. The standards were prepared from dried fresh NaCl and KCl. In this method water samples were atomized and sprayed into a burner and the intensity of light emitted by a particular spectral line was measured by a photoelectric cell and a galvanometer. Sulphate was estimated by gravimetric method. Spectrophotometer was used for the estimation of NO_3^-. In this type of photometry light is passed through an absorbing column of colored solution and directed upon the photosensitive device, which converts the radiant energy into electrical energy. Thus the current produced is measured by a sensitive voltmeter. The results were expressed in mg/l which were then converted into milliequivalents used for different plots during the interpretation of various parameters. Atomic absorption spectrophotometer was used for the estimation of Fe, Zn, Mn and Pb.

5.2 TEMPO-SPATIAL VARIATIONS OF PHYSICO-CHEMICAL CHARACTERISTICS OF DAL LAKE WATER

The summary of the results of various physico-chemical characteristics of Dal Lake water is presented in Tables 5.1 and 5.2 and the detail fluctuation in four season's i.e. spring, summer, autumn and winter is presented in Appendix II a,b,c and d.

5.2.1 Physico-chemical characteristics

5.2.1.1 Temperature

Temperature is an important parameter which effects on various bio-chemical reactions within the lacustrine environment. The surface water of the lakes is generally temperature equilibrated with the atmospheric temperature i.e. being highest in summer and lowest in winter. Temperature has a pronounced effect on water taste. At temperature range of 7^0C to 11^0C, water has a pleasant taste; however, at higher temperature it becomes tasteless and even does not quench the thirst.

The spatial variation of surface water temperature of Dal Lake is shown in Table 5.1, which depicts a slight variation being lower (~27^0C) nearer to inflow channels, viz; Talbal nala, Miraksha nala, Harshii Kul, Peshpaw nala, Shalimar nala; and higher (~27.8^0C) away from inflow channels.

Table 5.1 Summary of spatial variation of various physico-chemical parameters of Dal Lake water.

Parameters	Hazratbal basin	Boddal basin	Gagribal basin	Nagin basin	Whole lake
Temperature ^0C	-2.0-27.0	-5.7-27.6	-5.5-26.8	-4.3-27.8	-5.7-22.8
pH	8.0-9.6	8.2-9.7	7.4-9.6	8.0-9.6	7.4-9.7
E.C. ms/cm	312-398	320-394	345-420	313-417	312-420
T.D.S. mg/l	200-255	205-252	221-269	200.267	200-269
D.O. mg/l	4.2-12.4	4.4-12.2	4.5-12.0	4.0-11.2	4.0-12.4
Ca mg/l	12.2-45.7	10.8-26.7	11.3-43.7	10.1-26.2	10.1-45.7
Mg mg/l	5.2-16.2	4.2-10.5	4.4-15.9	3.7-10.3	3.7-16.2
Na mg/l	2.2-6.5	1.5-5.6	1.6-6.4	1.8-5.3	1.5-6.5
K mg/l	1.1-3.8	1.1-2.7	1.1-3.3	1.1-2.7	1.1-3.8
HCO_3 mg/l	45-201	34-128	37-198	37-120	34-201
Cl mg/l	10.5-28.2	7.5-15.1	10.3-25.2	7.3-20.7	3.7-28.2
SO_4 mg/l	1.8-6.7	1.5-3.9	1.8-6.2	1.2-3.7	1.2-6.7
NO_3 mg/l	1.1-2.5	1.0-2.4	4.6-13.9	2.5-8.6	1.0-13.9
Fe mg/l	0.24-1.29	0.18-1.24	0.32-1.42	0.18-1.18	0.18-1.29
Zn mg/l	0.10-0.87	0.09-0.82	0.13-0.93	0.06-0.085	0.06-0.92
Mn mg/l	0.027-0.063	0.024-0.057	0.029-0.069	0.026-0.059	0.024-0.069
Pb mg/l	0.003-0.019	0.001-0.014	0.002-0.021	0.001-0.013	0.001-0.021
SAR	0.15-0.23	0.19-0.28	0.23-0.31	0.21-0.27	0.15-0.31
%Na	10-12	11-13	12-15	11-14	10-15

Table 5.2 Summary of seasonal variation of various physico-chemical parameters of Dal Lake water.

Parameters	Spring			Summer			Autumn			Winter		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Temperature ^{0}C	5.0	18.2	11.0	22.5	27.8	25.7	18.5	27.6	23.0	-5.7	6.5	0.9
PH	7.6	9.2	8.5	8.9	9.7	9.4	8.8	9.6	9.2	7.4	8.9	8.4
EC μs/cm	334	401	371	312	370	344	316	405	369	351	420	384
TDS mg/l	214	257	239	200	237	220	202	259	236	224	269	246
D.O. mg/l	5.7	11.8	8.7	4.0	7.8	5.3	4.2	9.3	6.8	8.6	12.4	10.5
Ca mg/l	12.4	19.6	15.8	10.1	17.3	13.3	18.2	43.1	28.7	20.1	45.7	29.3
Mg mg/l	4.3	8.8	6.6	3.7	8.2	5.4	6.2	14.8	10.3	7.2	16.2	11.2
Na mg/l	1.8	4.2	3.0	1.5	3.9	2.5	3.8	6.4	4.9	4.2	6.5	5.4
K mg/l	1.1	2.5	1.8	1.1	2.4	1.5	2.0	3.4	2.6	2.1	3.8	2.7
HCO_3 mg/l	43	68	58	34	60	48	84	195	130	96	201	138
Cl mg/l	13.7	28.2	19.2	11.2	21.4	14.5	10.3	15.8	13.4	7.3	15.4	10.9
SO_4 mg/l	1.7	3.4	2.4	1.2	3.4	2.4	2.2	6.3	4.0	2.3	6.7	4.1
NO_3 mg/l	1.1	9.6	4.1	1.3	13.9	5.3	1.1	8.4	3.6	1.0	6.4	3.1
Fe mg/l	0.37	1.29	0.88	0.56	1.42	0.98	0.32	1.12	0.81	0.16	0.75	0.39
Zn mg/l	0.08	0.59	0.41	0.10	0.93	0.5	0.07	0.57	0.32	0.06	0.45	0.26
Mn mg/l	0.031	0.054	0.042	0.036	0.065	0.049	0.028	0.047	0.036	0.024	0.039	0.031
Ph mg/l	0.001	0.018	0.009	0.002	0.021	0.01	0.001	0.016	0.01	0.001	0.012	0.006

In other words, as we go away from the fresh water inlets the surface water temperature goes on increasing. The over all surface water temperature ranges from $-5.7^{0}C$ to $27.8^{0}C$. Dal Lake also shows some sort of surface water temperature variation within the different basins. At Hazratbal it varies from $-2^{0}C$ to $27^{0}C$, at Boddal from $-5.7^{0}C$ to $27.6^{0}C$, at Gagribal from $-5.5^{0}C$ to $26.8^{0}C$ and at Nagin from $-4.3^{0}C$ to $27.8^{0}C$ (Table 5.1). Though there is a less spatial variation in temperature regimes, the seasonal variations are quite large being highest in summer and lowest in winter as normally expected, which reflects the positive correlation with the atmospheric temperature. The highest temperature values of $22.5^{0}C$ to $27.6^{0}C$ with average value of $25.7^{0}C$ are recorded during summer and lowest values of $-5.7^{0}C$ to $6.5^{0}C$ with average value of $0.9^{0}C$ during winter. Spring and autumn seasons recorded the moderate values of $5^{0}C$ to $18.2^{0}C$ and $18.5^{0}C$ to $27.6^{0}C$ with average values of $11.0^{0}C$ and $23.0^{0}C$ respectively (Table 5.2).

The only exception to the normal trend of surface water temperature variation is observed at sites GB7, GB11, GB12, GB13 and GB14 of Gagribal basin where the inflow of sewage drains is maximum (Appendix II).

5.2.1.2 pH

pH is the measure of hydrogen ion concentration. Depending on the concentration of hydrogen ions, water is said to be acidic or alkaline.

* As the ground water has not been taken in to account during the present study thus the temperature variation has also not been delt.

Most natural waters are generally alkaline due to presence of sufficient quantity of carbonates, which change diurnally and seasonally due to variation in photosynthetic activity. pH has no direct adverse effect on health. However, a lower value (<4) and higher value (>8.5) will produce sour and alkaline taste respectively. Lower values of pH causes corrosion and higher values hasten the scale formation in water heating apparatus and reduce the germicidal potential of chlorine. The WHO (1991) has setup the pH norms of 6.5 to 8.5 suitable for drinking purposes. However the freshwaters of Kashmir are generally alkaline due to the presence of sufficient quantities of carbonates and bicarbonates of calcium and magnesium, which owe their origin to the lacustrine deposits in the Kashmir valley. The pH of Dal Lake water is also on alkaline side and varies from 7.4 to 9.7 (Table 5.1). At both Hazratbal and Nagin basin pH vary between 8.0 to 9.6 whereas at the Boddal and Gagribal basins it varies from 8.2 to 9.7 and 7.4 to 9.6. Lower pH values at sites GB1, GB4, GB9, GB10 (Appendix II), within Gagribal basin are close to the sewage disposal and houseboats. Higher values of 8.9 to 9.7 with an average value of 9.4 are recorded in warm water conditions (summer) and lower values of 7.4 to 8.9 with an average value of 8.4 in cold water conditions (winter). Whereas intermediate values of 7.6 to 9.2 and 8.8 to 9.6 with average values of 8.5 and 9.2 are recorded during spring and autumn respectively (Table 5.2).

5.2.1.3 Total Dissolved Solids

The total dissolved solids in natural waters are composed mainly of bicarbonates, chlorides, sulphates and nitrates of calcium, magnesium, sodium, potassium and iron, etc. The concentration of TDS is generally low (20ppm) in the high rainfall areas and high (>100,000 ppm) in some desert brines (Karanth , 1987). The TDS concentration in Dal Lake water ranges from 200 mg/l to 269 mg/l. Among various basins the Gagribal basin recorded the higher TDS values varying from 221 mg/l to 269 mg/l whereas the Hazratbal basin recorded the lower values varying from 200 mg/l to 255 mg/l. TDS concentration in Boddal basin vary from 205 mg/l to 252 mg/l and in Nagin basin from 200 mg/l to 267 mg/l (Table 5.1). Maximum values (224 mg/l to 269 mg/l) are recorded in winter and minimum (200 mg/l to 237 mg/l) in summer. The intermediate values of 214 mg/l to 257 mg/l and 202 mg/l to 259 mg/l are recorded in spring and autumn respectively. Overall higher average values are observed in winter (246 mg/l) followed by spring (239 mg/l), autumn (236 mg/l) and summer (220 mg/l) in a decreasing order. Gagribal Basin shows a pronounced seasonal fluctuation in TDS, being higher in winter (Table 5.2).

5.2.1.4 Specific Electric Conductance

* High seasonal fluctuation of TDS value is mainly due to domestic sewage waste solids and fertilizers used.
* The remedial measures are mentioned in Chapter VI.
* Due to the variation in the anthropogenic sources in different basins
* Due to variation in tourist influx and biological activities in different seasons.

water ranges from 1 μS /cm to 5 μS /cm. An increase in conductance in the water indicates addition of ions. Temperature increase of $1^{0}C$ increases the conductance by about 2%. As the specific electric conductance shows positive correlation with total dissolved solids, all the sites in the study area are positively correlated with TDS. The X specific electrical conductance varies from 312 μS /cm to 420 μS /cm (Table 5.1). A comparison of various basins reveals that in Hazratbal basin specific electric conductance values fluctuate from 312 μS /cm to 398 μS /cm; in Boddal basin from 320 μS /cm to 394 μS /cm; in Gagribal basin from 345μS /cm to 420 μS/cm and in Nagin basin from 313 μS /cm to 417 μS /cm. Maximum values are recorded during winter (351 μS /cm to 420 μS /cm) with an average value of 384 μS/cm. The specific electric conductance values during spring varied from 334 μS /cm to 401 μS /cm with an average value of 371 μS /cm; during summer from 312 μS /cm to 370 μS /cm with an average value of 344 μS /cm and during autumn from 351 μS /cm to 420 μS /cm with an average value of 384 μS/cm (Table 5.2).

5.2.1.5 Dissolved Oxygen

Dissolved oxygen concentration is essential for the maintenance of higher forms of biological life in aquatic environment. Oxygen saturated waters are normally non polluted and have pleasant taste. The amplitude of dissolved oxygen in Dal Lake water ranges from

* X The minimum EC values in summer is attributed to the high dilution and intake of ions by plants where as the higher value is due to less dilution and decomposition of aquatic plant and animals during other seasons which has already been described in Chapter VI

basin varies from 4.2 mg/l to 12.4 mg/l; in Boddal basin from 4.4 mg/l to 12.2 mg/l; in Gagribal basin from 4.5 mg/l to 12.0 mg/l and in Nagin basin from 4.0 mg/l to 11.2 mg/l (Table 5.1). Temporal variation reveals that higher concentration is recorded in winter (8.6 mg/l to 12.4 mg/l) X and lower in summer (4.0 mg/l to 7.8 mg/l). During spring and autumn dissolved oxygen concentration varies from 5.7 mg/l to 11.8 mg/l and 4.2 mg/l to 9.3 mg/l respectively (Table 5.2). The highest average value (10.5 mg/l) was recoded in winter followed by spring (8.7 mg/l), autumn (6.8 mg/l) and summer (5.3 mg/l) in a decreasing order.

5.2.2 Major ion variation

5.2.2.1 Calcium

Being present in high concentration in the earth's crust, calcium is commonly found in abundance in freshwaters. It is an important nutrient for living organisms in a desirable limit. Generally, calcium concentration in natural water varies from 10 mg/l to 100 mg/l depending upon the complex flow history of water through chemically different geological formations and the interaction between the two. In the present study area the annual amplitude of calcium concentration in surface water samples show varied, fluctuation from 10.1 mg/l to 45.7 mg/l (Table 5.1). A comparison of various basins (Fig. 5.1a) reveal that Hazratbal basin recorded highest concentration of 12.2 mg/l to 45.7 mg/l, higher being close to the inflow channel sites such as HZ4, HZ7, HZ12, HZ15 and the Nagin basin recorded lowest concentration of 10.1mg/l to 26.2 mg/l, the lowest being towards deeper sites NB4, NB9

* X The low concentration of Dissolved oxygen during summer is because of the abundant growth of aquatic plants where as the higher value in winter is due to less biological activities, already mentioned in Chapter VI.

Fig.5.1a. Spatial variation of Ca^{++} and Mg^{++} in Dal Lake water.

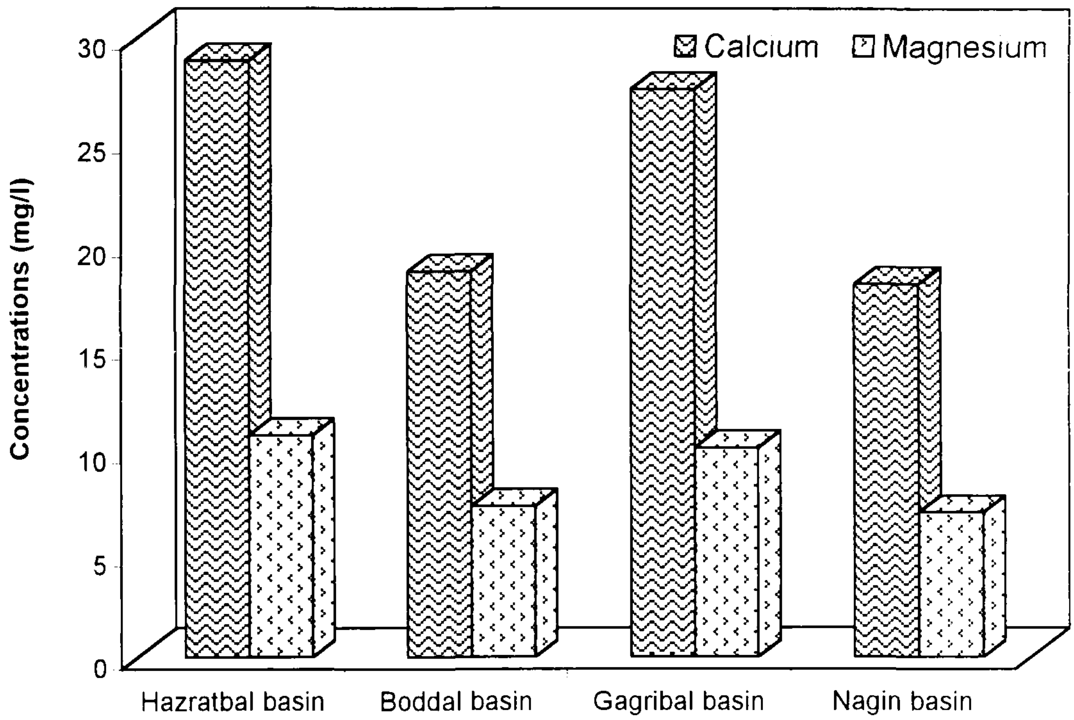
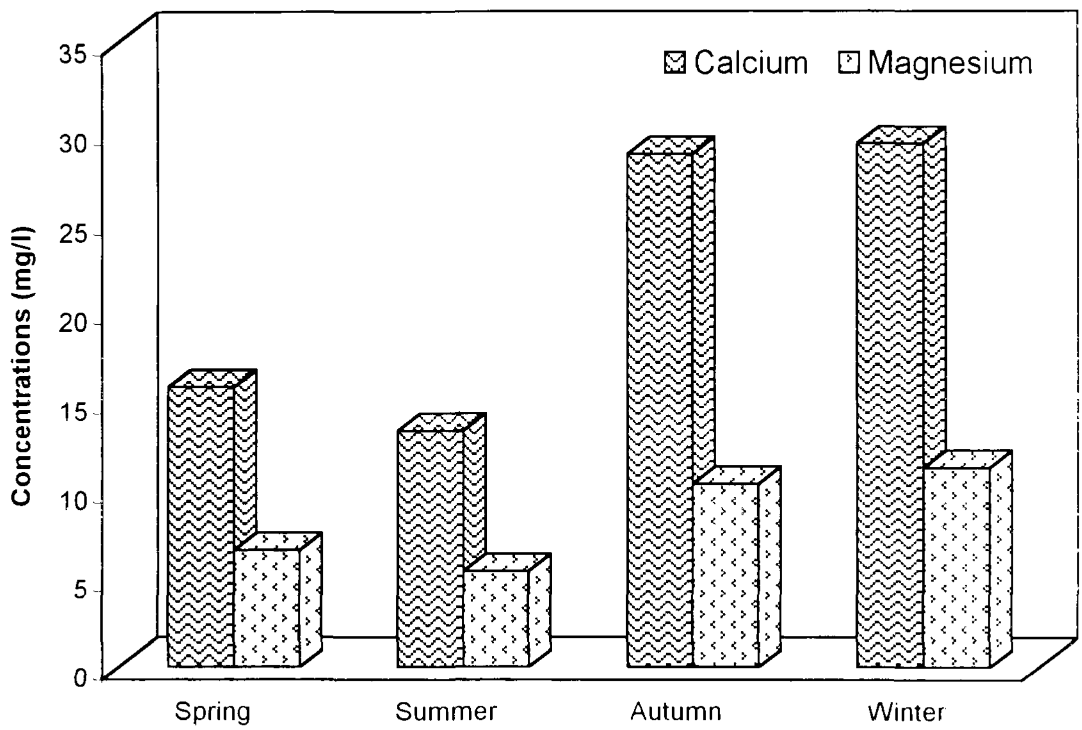


Fig.5.1b. Seasonal variation of Ca^{++} and Mg^{++} in Dal Lake water.



At Gagribal basin calcium ranges from 11.3 mg/l to 43.7 mg/l and at Boddal it varies from 10.8 mg/l to 26.7 mg/l. Highest calcium concentration is recorded in winter (Fig. 5.1b) (20.1 mg/l to 45.7 mg/l) with an average value of 29.3 mg/l and the lowest in summer (10.1 mg/l to 17.3mg/l) with an average value of 13.3 mg/l where as the spring (12.4 mg/l to 19.6 mg/l) and autumn (18.2 mg/l to 43.1 mg/l) with an average values of 15.8 mg/l and 28.7 mg/l are the intermediates between the two extremes (Table 5.2).

5.2.2.2 Magnesium

Like calcium, magnesium is also found in all types of natural waters. Generally magnesium concentration remains lower than calcium, both found in the ratio of 3:1.

In the study area magnesium concentration in water samples is somehow similar to calcium and vary from 3.7 mg/l to 16.2 mg/l. Comparison of various basins (Fig. 5.1a) reveal that in Hazratbal basin magnesium concentration vary from 5.2 mg/l to 16.2 mg/l, in Boddal from 4.2 mg/l to 10.5 mg/l, in Gagribal from 4.4mg/l to 15.9 mg/l and in Nagin from 3.7mg/l to10.3 mg/l (Table 5.1). Seasonally the highest magnesium concentration is recorded in winter (Fig. 5.1b) which ranges from 7.2 mg/l to 16.2 mg/l with an average value of 11.2 mg/l and lowest in summer which ranges from 3.7 mg/l to 8.2 mg/l, the average being 5.4 mg/l. In spring and autumn seasons magnesium concentration varies from 4.3 mg/l to 8.8 mg/l and 6.2 mg/l to 14.8 mg/l with average values of 6.6 mg/l and 10.3 mg/l respectively (Table 5.2).

5.2.2.3 Sodium

Among the monovalent components sodium in an important cation found in natural waters, sodium salts being highly soluble does not participate in precipitation reactions. ✗ The WHO (1993) has recommended the acceptable limit of 200 mg/l but the higher concentration may be harmful not only to human population but also effects aquatic organisms and deteriorates the crop yielding properly of agricultural land. Sodium concentration in Dal Lake surface water ranges from 1.5 mg/l to 6.5 mg/l. Its concentration in Boddal and Nagin varies from 1.5 mg/l to 5.6 mg/l and 1.8 mg/l to 5.3 mg/l (Fig. 5.2). While at Hazratbal it varies from 2.2 mg/l to 6.5 mg/l and at Gagribal from 1.6 mg/l to 6.4 mg/l (Table 5.1). It is observed that seasonally high sodium concentration (4.2 mg/l to 6.5 mg/l) is recorded during winter with an average value of 5.4 mg/l and low (1.8 mg/l to 3.9 mg/l) during summer (Fig. 5.2b) with an average value of 2.5 mg/l. The sodium concentration varies from 1.8 mg/l to 4.2 mg/l and 3.8 mg/l to 6.4 mg/l with average values of 3.0 mg/l and 4.9 mg/l during spring and autumn respectively (Table 5.2).

5.2.2.4 Potassium

Despite its over abundance in earths crust, potassium occurs in small quantities in natural waters than sodium, as potassium bearing source rocks are resistant to chemical weathering.

✗ The Reference pointed out have been cited under the heading of Additional References in the thesis.

Fig.5.2a. Spatial variation of Na^+ and K^+ in Dal Lake water.

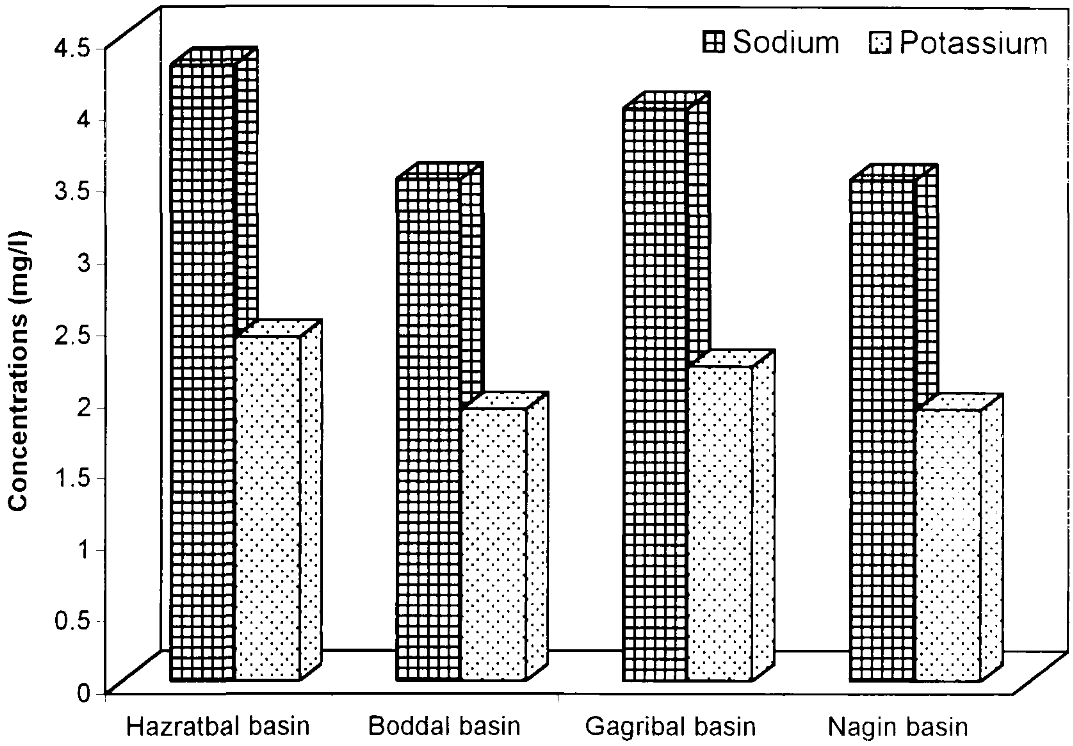
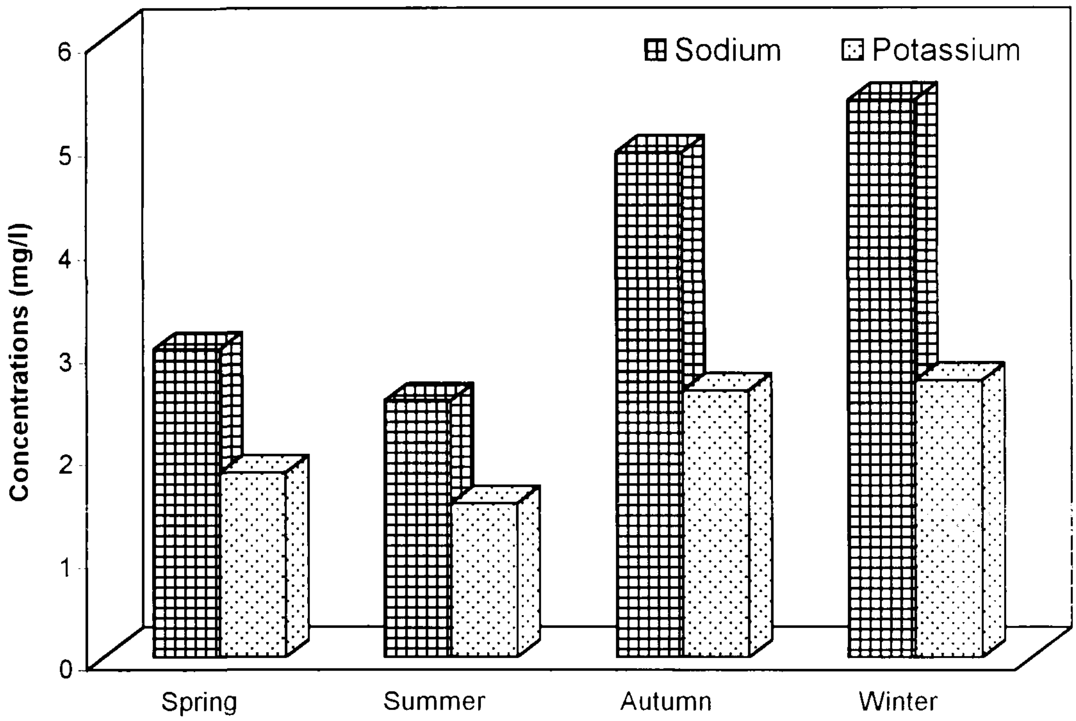


Fig.5.2a. Seasonal variation of Na^+ and K^+ in Dal Lake water.



The WHO (1993) has given a permissible limit of 12 mg/l. but excessive concentrations are harmful both for plants and animals. Potassium being less mobile occurs almost in homogeneous concentration as compared to sodium. Potassium concentration in surface water of Dal Lake ranges from 1.1 mg/l to 3.8 mg/l. Basin wise investigation (Fig. 5.2a) reveals that all the four basins recorded minimum potassium concentration of 1.1 mg/l and a maximum value of 3.8 mg/l at Hazratbal, 3.3 mg/l at Gagribal and 2.7 mg/l at both Boddal and Nagin basins (Table 5.1). Seasonal variation (Fig. 5.2b) reveals that in spring and summer potassium concentration shows a bit similar range of 1.1 mg/l to 2.5 mg/l and 1.1 mg/l to 2.4 mg/l whereas in autumn and winter it varies from 2.0 mg/l to 3.4 mg/l and 2.1 mg/l to 3.8 mg/l respectively. Similarly a slight higher average concentration (2.7 mg/l) is recorded in winter as compared to autumn (2.6 mg/l) followed by spring (1.8 mg/l) and summer (1.5 mg/l) in a decreasing order (Table 5.2).

5.2.2.5 Bicarbonates

Besides other constituents carbonates and bicarbonates together constitute the most of the total alkalinity in natural waters. Generally bicarbonates are not harmful to human health, but are highly objectionable for some of the industrial uses. The bicarbonate concentration in Dal Lake surface water shows a wider range, varying from a low of 34 mg/l to a high of 201 mg/l (Table 5.1). Basin wise variations (Fig. 5.3a) show Hazratbal ranking high (45 mg/l to 201 mg/l) and Nagin ranking low (37 mg/l to 120 mg/l) i.e. it is positively correlated with calcium and magnesium.

Fig.5.3a. Spatial variation of HCO_3^- and Cl^- in Dal Lake water.

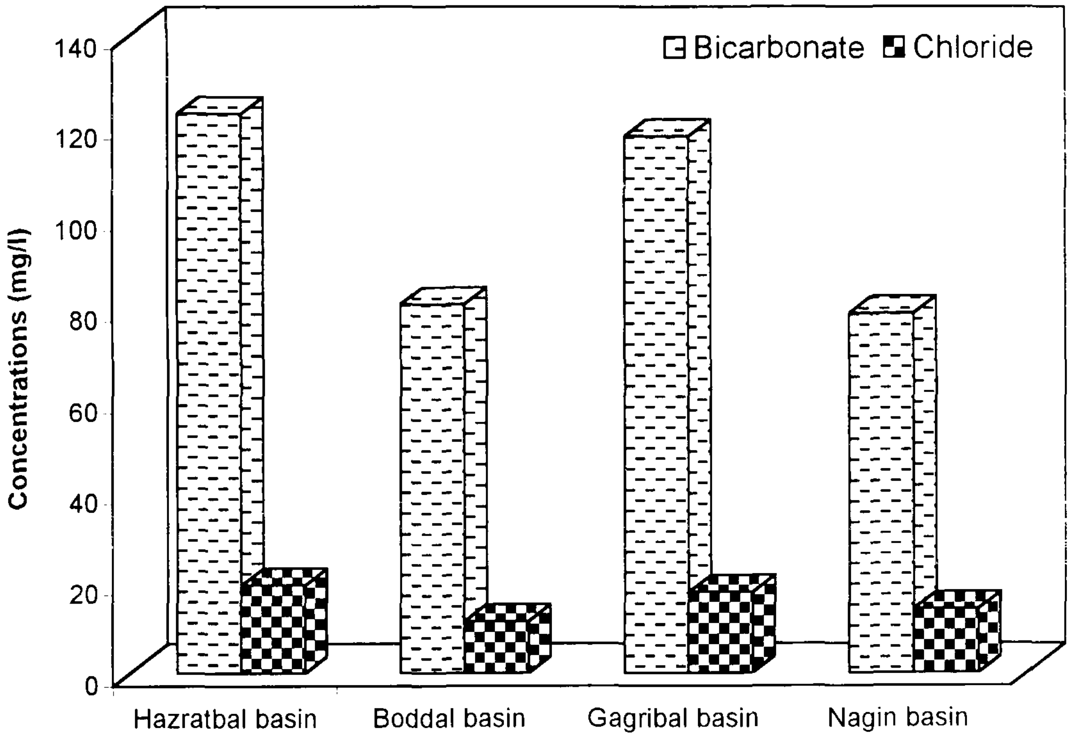
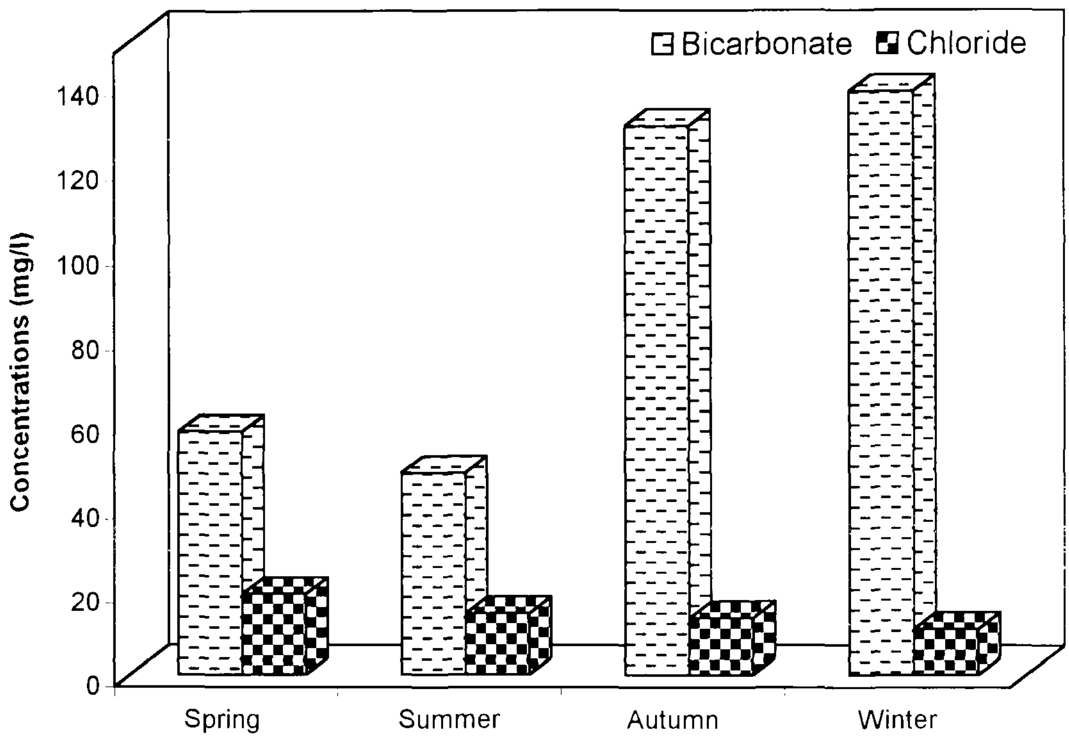


Fig.5.3b. Seasonal variation of HCO_3^- and Cl^- in Dal Lake water.



The higher values are recorded at sites close to the inflow channels such as HZ7, HZ12, HZ15, and sewer drains such as GB6, GB13 (Appendix II). At Boddal it vary from 34 mg/l to 128 mg/l and at Gagribal from 37mg/l to198 mg/l. Seasonally highest average concentration (138 mg/l) is recorded in winter and lowest (48 mg/l) in summer. Similarly higher range values are recorded in winter (96 mg/l to 201 mg/l) and lower in summer (34 mg/l to 70 mg/l) and spring (43 mg/l to 68 mg/l) respectively (Fig. 5.3b). Its concentration in autumn is comparative high and ranges from 84 mg/l to 195 mg/l with an average value of 130 mg/l (Table 5.2).

5.2.2.6 Chloride

XChlorides being highly soluble, are mostly present in all types of water, however, its concentration remains low as compared to bicarbonates. Usually chloride content is more in arid regions than in humid regions. It is harmless up to 1500 mg/l, but the WHO (1993) has recommended a maximum permissible limit of 250 mg/l. However, very high concentration may harm some plants and causes corrosive effects. The chloride concentration in surface water samples of Dal Lake ranges from 7.3 mg/l to 28.2 mg/l (Table 5.1). The noteworthy feature of the chloride is its highest concentration at Hazratbal (10.5 mg/l to 28.2 mg/l) and lowest at Nagin (7.3 mg/l to 20.7 mg/l) (Fig. 5.3a). The chloride

* X The higher concentration of Chloride is due to the presence of large amount of organic matter where as higher value of Nitrate is due to input of fertilizers and increase of tourist influx. The other ions show higher value in winter because of less dilution and decrease in biological activity, already mentioned in Chapter VI

recorded nearer to inflow channels and sewer drains. Seasonal trends (Fig. 5.3b) of the anion depicts its maximum value (13.7 mg/l to 28.2 mg/l) with an average value of 19.2 mg/l in spring and minimum (7.3 mg/l to 15.4 mg/l) with an average value of 10.9 mg/l in winter whereas summer (11.2 mg/l to 21.4 mg/l) with an average value of 14.5 mg/l and autumn (10.3 mg/l to 15.8 mg/l) with an average value of 13.4 mg/l, posses intermediate positions (Table 5.2).

5.2.2.7 Sulphate

Sulphate is a naturally occurring anion found in smaller quantities than chloride in all types of water. Most of its salts are soluble in water; however, it may under go transformation to form sulphur and hydrogen sulphate, depending upon the redox potential of the water. WHO (1993) have recommended a permissible limit of 400mg/l and desirable level of 200 mg/l, however, the overall amplitude of sulphate in Dal Lake surface water fluctuates from 1.2 mg/l to 6.7 mg/l. Spatial variation (Fig. 5.4a) reveals that sulphate concentration at Hazratbal ranges from 1.8 mg/l to 6.7 mg/l, at Boddal from 1.5 mg/l to 3.9 mg/l, at Gagribal from 1.8 mg/l to 6.2 mg/l and at Nagin from 1.2 mg/l to 3.7 mg/l (Table 5.1). Seasonal investigations (Fig. 5.4b) reveals that sulphate concentration does not show wide variations, comparatively higher values (2.3 mg/l to 6.7 mg/l) are recorded in winter than in summer (1.2 mg/l to 3.4 mg/l). Both spring and autumn season recorded intermediate values of 1.7 mg/l to 3.4 mg/l and 2.2 mg/l to 6.3 mg/l respectively (Table 5.2).

Fig.5.4a. Spatial variation of SO_4^{--} and NO_3^- in Dal Lake water.

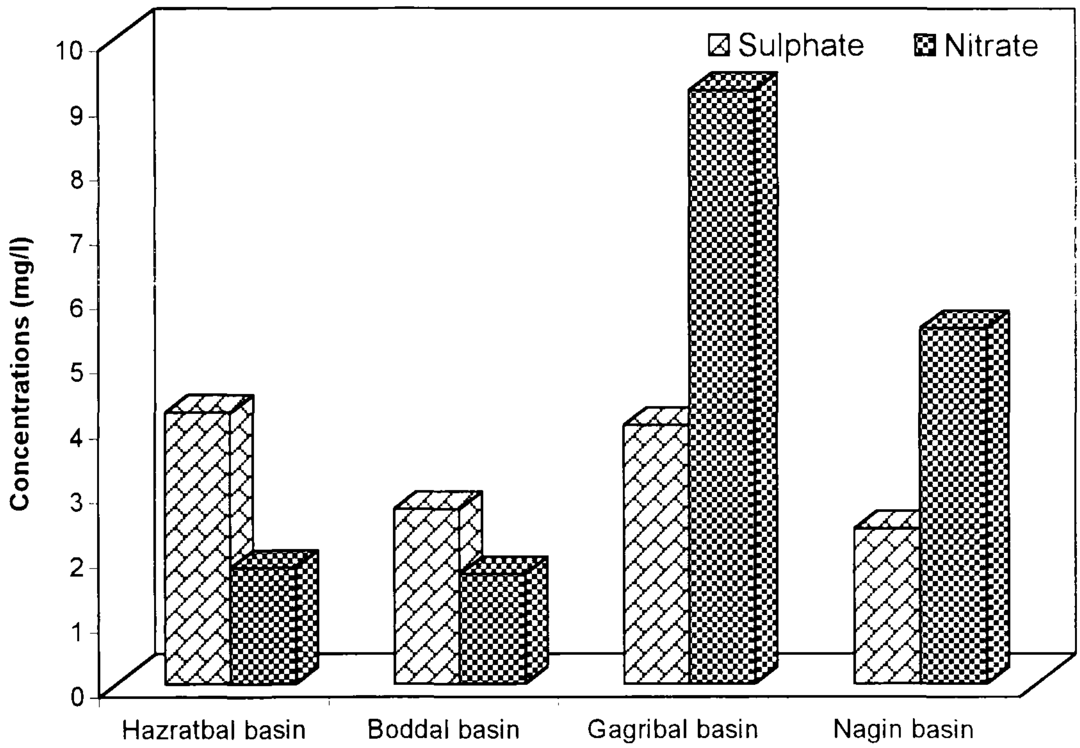
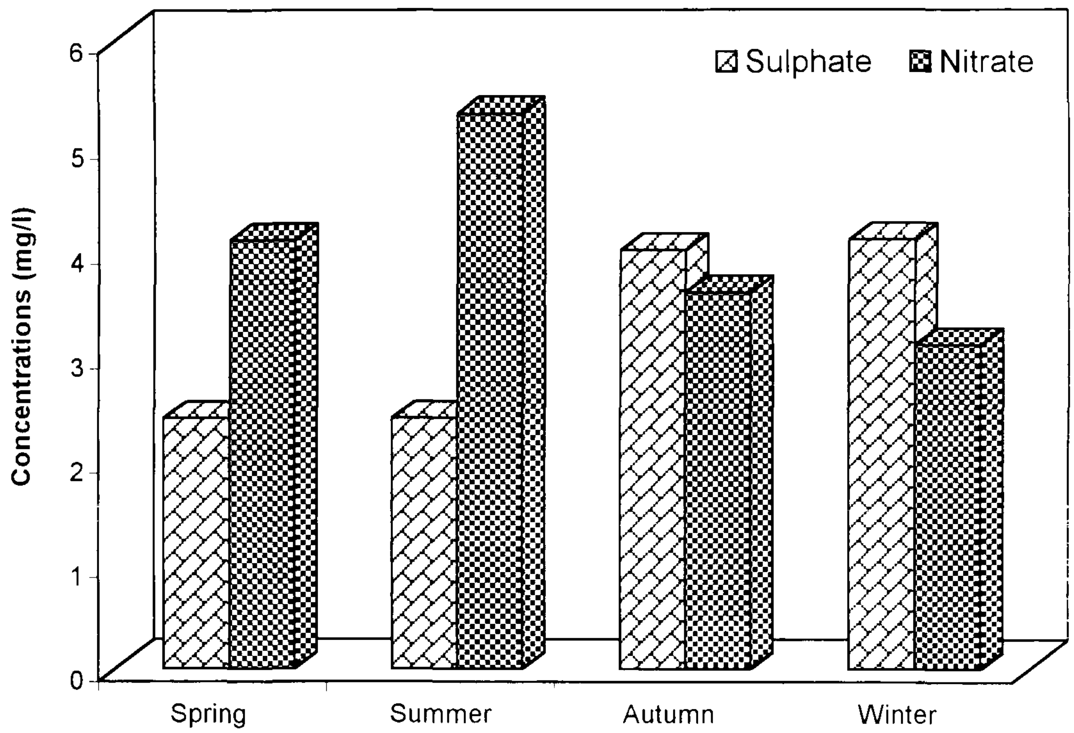


Fig.5.4b. Seasonal variation of SO_4^{--} and NO_3^- in Dal Lake water.



Similarly, winter season recorded slight higher average concentration (4.1 mg/l) than autumn (4.0 mg/l) whereas both spring and summer recorded the similar average value of 2.4 mg/l.

5.2.2.8 Nitrate

In the natural waters nitrate exists as the oxidized form of nitrogen, which itself is abundantly found in gaseous form in atmosphere and associated mostly with clays in the lithosphere. Nitrate concentration in precipitates varies between 0.3mg/l to 2.5 mg/l (Junge, 1963); however, higher concentrations are found in agricultural areas because of fertilizer utilization. The WHO (1993) has proposed a maximum concentration limit of 50 mg/l in drinking water. Nitrate concentration in water samples of study area ranged between 1.0 mg/l and 13.9 mg/l. Gagribal recorded the highest concentration varying from 4.6 mg/l to 13.9 mg/l and Boddal recorded the lowest varying from 1.0 mg/l to 2.4 mg/l (Fig. 5.4a). Nagin also recorded higher concentration (2.5 mg/l to 8.6 mg/l) as compared to Hazratbal (1.1 mg/l to 2.5 mg/l) (Table 5.1). The higher values of nitrate are recorded at sites GB1,GB7 and BG12 close to houseboats, human settlements, restaurants, sewage drains etc, while the lowest values are recorded at freshwater sites HZ1,HZ3 and HZ8 inflow channels (Appendix II). Seasonally summer observed the higher concentration (Fig. 5.4b) ranging between 1.3 mg/l and 13.9 mg/l with an average value of 5.3 mg/l and winter observed the lower concentration ranging between 1.0 mg/l and 6.4

mg/l with an average value of 3.1 mg/l whereas moderate values of 1.1 mg/l to 9.6 mg/l and 1.1 mg/l to 8.4 mg/l are recorded in spring and autumn with average values of 4.1 mg/l and 3.6 mg/l respectively (Table 5.2).

5.2.2.9 Sodium Adsorption Ratio

The suitability of water for irrigation is contingent on the effects of the mineral constituents of the water on both the plants and soil. The parameters such as sodium adsorption ratio (SAR) and percentage sodium ratio (%Na) are estimated to assess the suitability of water for irrigation purpose. EC and Na concentration are very important in classifying irrigation water. Water used for irrigation always contains measurable quantities of substances, which include a relatively small but important amount of dissolved solids originating from the weathering of the rocks and soils and from the dissolution of lime, gypsum and other salt sources as water flows over or percolate through them. The salts present in water bodies affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Depending upon the concentration of soluble salts, irrigation water can be classified as low (EC < 250 μS cm/l), medium (250 to 750 μS cm/l) high (750 to 2250 μS cm/l) and very high (2250 to 5000 μS cm/l) salinity zones. High salt concentration in water leads to the formation of saline soil, a high sodium concentration leads to development of alkaline soil. The sodium or alkaline hazards in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of sodium absorption ratio which can be estimated by

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

In the study area the calculated SAR values range from 0.15 to 0.31 the lower values being recorded from sites close to freshwater inlets (Hazratbal basin), while higher values are recorded from sites fed by sewage drains (Gagribal basin) (Table 5.1). However, most of the samples show low salinity and low to medium alkalinity and the waters can be used for irrigation on almost all the soils.

The calculated value of %Na in the study area ranges between 10 to 15. A maximum of 60% Na is recommended for irrigation water as per the BIS standards. In the study area all the water samples fall within the permissible limit. According to Wilcox diagram (1955) the water of the study area is excellent to good for irrigation purposes.

5.2.3 Trace element variation

5.2.3.1 Iron

Iron, like manganese is also naturally occurring metal, mainly from soil and rocks and in ground water occurs in less concentration reflecting its low geochemical mobility. It plays an important role in the life cycle of plants and animals. The overall concentration of Iron in Dal

Due to time constrain it could not be plotted hence in future it will be included in the publication of results.

lake waters ranges between 0.16mg/l to 1.42mg/l, which is within the permissible limit of WHO (1993). Basin wise investigation (Fig. 5.5a) reveals that Iron concentration at Hazratbal basin ranges from 0.24mg/l to 1.29 mg/l, at Boddal basin from 0.32 mg/l to 1.24 mg/l, at Gagribal basin from 0.32 mg/l to 1.42 mg/l and at Nagin basin from 0.18mg/l to 1.18 mg/l (Table 5.1). Seasonal investigations reveals that Iron concentration does not show wide variations, recorded higher values (0.56mg/l to 1.42mg/l) with an average value of 0.98mg/l in summer and lower values of 0.16mg/l to 0.75mg/l with an average value of 0.39mg/l in winter. While in autumn it ranges between 0.32 mg/l to 1.12 mg/l, with an average value of 0.81 mg/l and in spring from 0.37 mg/l to 1.29 mg/l with an average value of 0.88mg/l and posses intermediate position between the two extremes (Table 5.2).

5.2.3.2 Zinc

Zinc is a common element, essential for plants and animals, particularly in human being where it plays a vital role in the functioning of various enzymes, protein synthesis and carbohydrate metabolism. (Taylor and Demaye, 1980). Main sources of zinc pollution are the impurities from fertilizers, fungicides and sewage sludge. WHO (1993) have prescribed highest desirable limit of 5.0mg/l and the maximum permissible limit of 15.0 mg/l in drinking water. However in the study area zinc concentration is much lower than WHO desirable limit and ranges between 0.06mg/l to 0.93 mg/l.

Fig.5.5a Spatial variation of Fe and Zn in Dal Lake water.

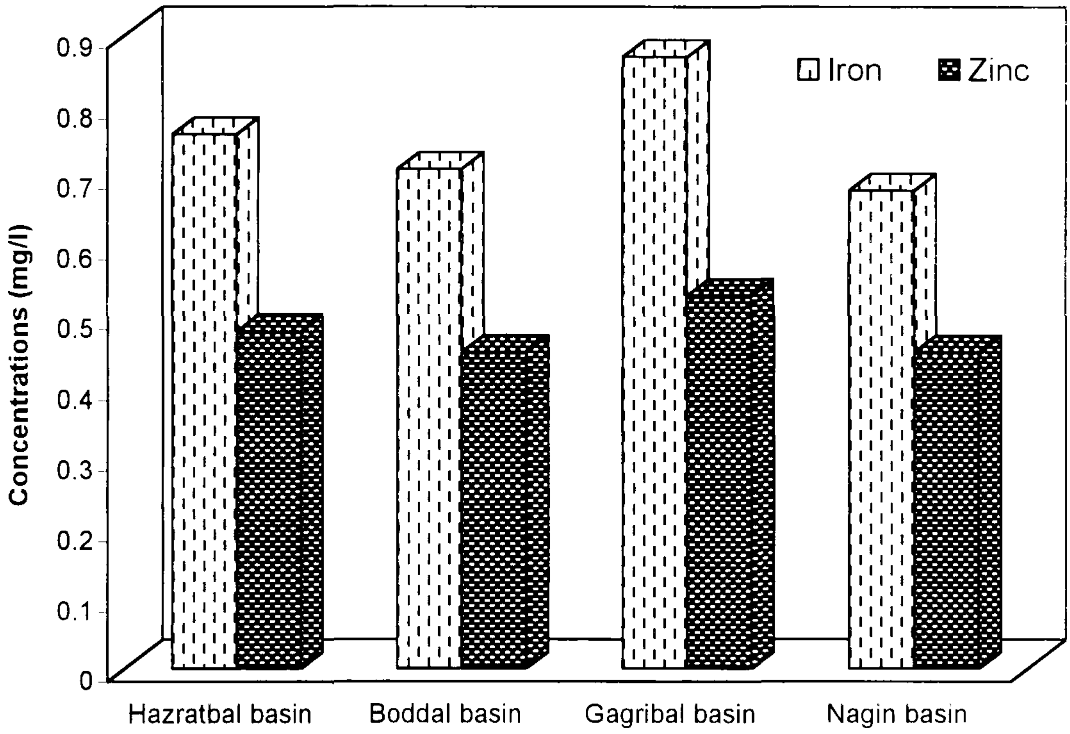
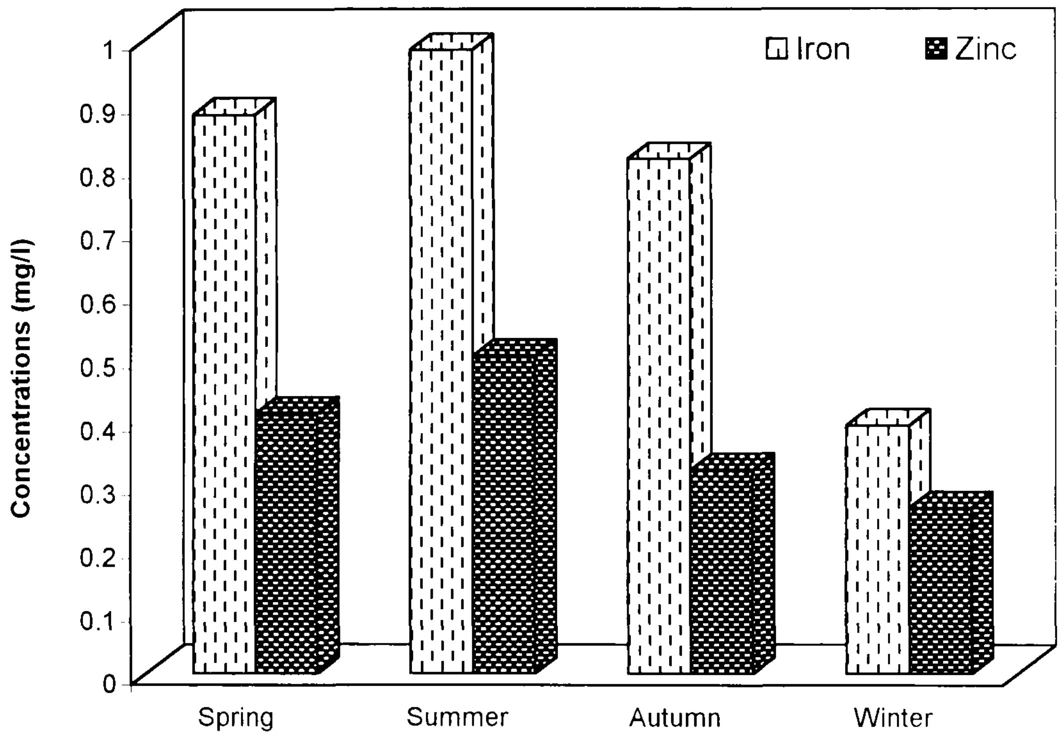


Fig.5.5b Seasonal variation of Fe and Zn in Dal Lake water.



A comparison of various basins of Dal lake (Fig. 5.5a) reveals that Gangribal basin recorded comparatively higher values (0.13 mg/l to 0.93mg/l) at site GB1, GB4, GB9 and GB10 (Appendix II) which are close to the sewage drains and a lower concentration 0.06 mg/l to 0.85 mg/l was recorded in Nagin basin. Hazratbal basin again recorded higher values ranging between 0.1 mg/l to 0.87 mg/l while at Boddal basin it vary from 0.09 mg/l to 0.82 mg/l (Table 5.1). Temporal variations (Fig. 5.5b) reveals that slight higher range values of 0.10 mg/l to 0.93 mg/l with an average value of 0.5 mg/l are recorded in summer followed by spring (0.08 mg/l to 0.59 mg/l) with an average value of 0.41 mg/l and autumn (0.07 mg/l to 0.57mg/l) with an average value of 0.32 mg/l in a decreasing order (Table 5.2).

5.2.3.3 Manganese

X Manganese is a naturally derived pollutant found in minor quality in groundwater. Its main sources are sedimentary and metamorphic rocks. In most groundwaters, under reducing conditions manganese concentration above 1mg/l are relatively rare, but values below to 0.05mg/l will have an adverse affect on the portability of water. However, higher concentration upto 42mg/l can be observed in thermal waters (White *et al.* 1963). WHO (1993) has recommended a permissible limit of 0.5mg/l and desirable level of 0.05 mg/l in drinking water. In Dal lake surface waters manganese concentration ranges

The lower concentration of Mn is because of abundant growth of aquatic plants which use Mn for their biological activities and the remedial measures are selective De-weeding and improvement of navigation routes, which has already been mentioned in Chapter VI.

Fig.5.6a Spatial variation of Mn and Pb in Dal Lake water.

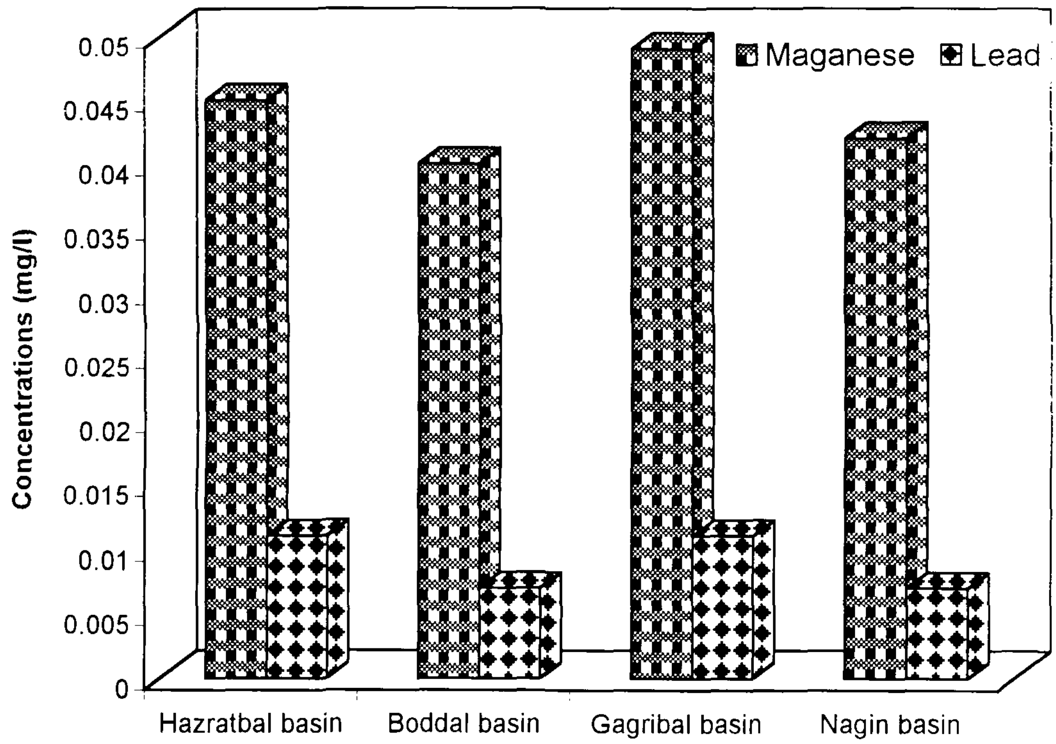
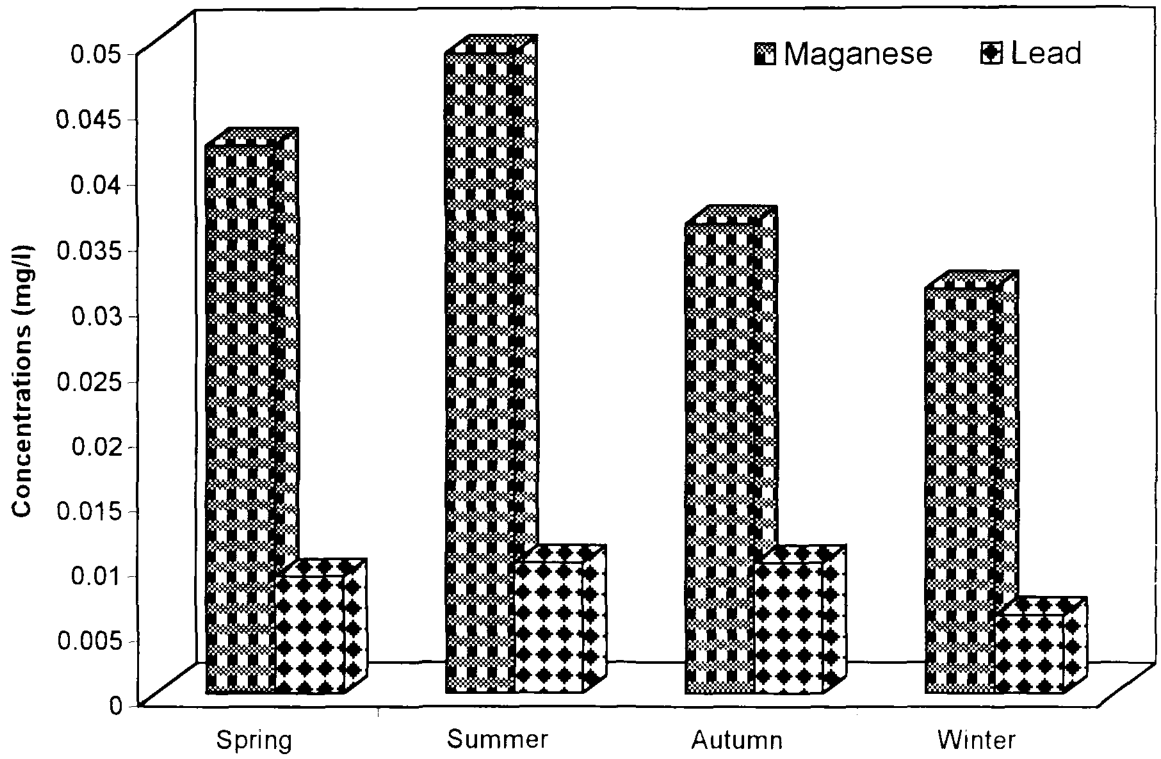


Fig.5.6b Seasonal variation of Mn and Pb in Dal Lake water.



Spatial variation (Fig. 5.6a) reveals that there was no marked difference in manganese concentration among various basin of Dal lake, however Gagribal basin recorded slight higher concentration of 0.029mg/l to 0.065 mg/l followed by Hazratbal basin (0.027mg/l to 0.063mg/l), Nagin basin (0.026mg/l to 0.059 mg/l) and Boddal basin (0.024 mg/l to 0.057 mg/l in a decreasing order (Table 5.1). It is observed that seasonally higher manganese concentration (0.036mg/l to 0.065 mg/l) is recorded in summer with an average value of 0.049 mg/l and lower (0.024mg/l to 0.039mg/l) during winter with an average value of 0.031mg/l (Fig. 5.6b). whereas the manganese concentration vary from 0.031mg/l to 0.054mg/l and 0.028mg/l to 0.047mg/l with average values of 0.042mg/l and 0.036mg/l during spring and autumn respectively (Table 5.2).

5.2.3.4 Lead

It is a toxic element found in low concentration in groundwaters because of the low solubility of its compounds. Mostly it enters the ground water by motor vehicle exhaust gases, lead containing pesticides and fertilizers etc. It has harmful effects on human health and causes loss of appetite, irritation, headache and vomiting in higher concentration. WHO (1993) has recommended a maximum permissible limit of 0.1mg/l and highest desirable limit of 0.05mg/l in drinking water. However in the water samples of Dal lake its concentration is very low ranging between 0.001 mg/l to 0.021 mg/l. Comparison of various basins (Fig. 5.6a) reveals that in Hazratbal basin lead concentration vary from 0.003 mg/l to 0.019mg/l, in Boddal basin from 0.001 mg/l to 0.014mg/l, in Gagribal basin from 0.002mg/l to 0.021 mg/l and in Nagin basin from 0.001 mg/l to 0.013 mg/l (Table 5.1). Seasonal investigation (Fig. 5.6b) reveals that except the summer season all seasons recorded similar minimum concentration of 0.001mg/l and a maximum of 0.018 in spring, 0.016 mg/l in autumn and 0.012 mg/l in winter, while in summer it vary from 0.002 mg/l to 0.021mg/l with an average values of 0.010 mg/l (Table 5.2).

5.3 CHEMICAL EVOLUATION OF DAL LAKE

5.3.1 Dal Lake water facies

Most freshwaters can be considered as solutions of three cationic (calcium, magnesium and alkalis) and three anionic constituents (chlorides, sulphates and carbonates-bicarbonates). The chemistry of waters may be represented conveniently by trilinear plotting (Hem, 1959), which are useful in bringing about the chemical relationships among different waters in more definite terms than is possible with other plotting methods. One of the most useful diagram, which is an effective tool in segregating the chemical data for critical study and representing and comparing water quality analyses, is developed by Piper known widely as Piper trilinear diagram (Piper, 1944). Here the concentration of cations and anions are expressed as percentages of total cations and anions respectively. In Dal Lake the water types were determined on the basis of their chemical composition. The concentration of the major cation and anions obtained in the laboratory were plotted on standard Piper trilinear diagram (Fig. 5.7) For using the diagram mg/l concentration values were converted to meq/l values.

The chemical data plotted on the diagram shows following trends:

As far as the cation triangle is concerned the data concentrate parallel to the Ca^{++} side of the triangle implying large-scale variations in the Ca^{++} content for much less variable Mg^{++} . The triangle also depicts that Ca^{++} and Mg^{++} are the two abundant cations, where as in the anion triangle all the samples cluster towards the expected bicarbonate end as bicarbonate is the most dominant anion.

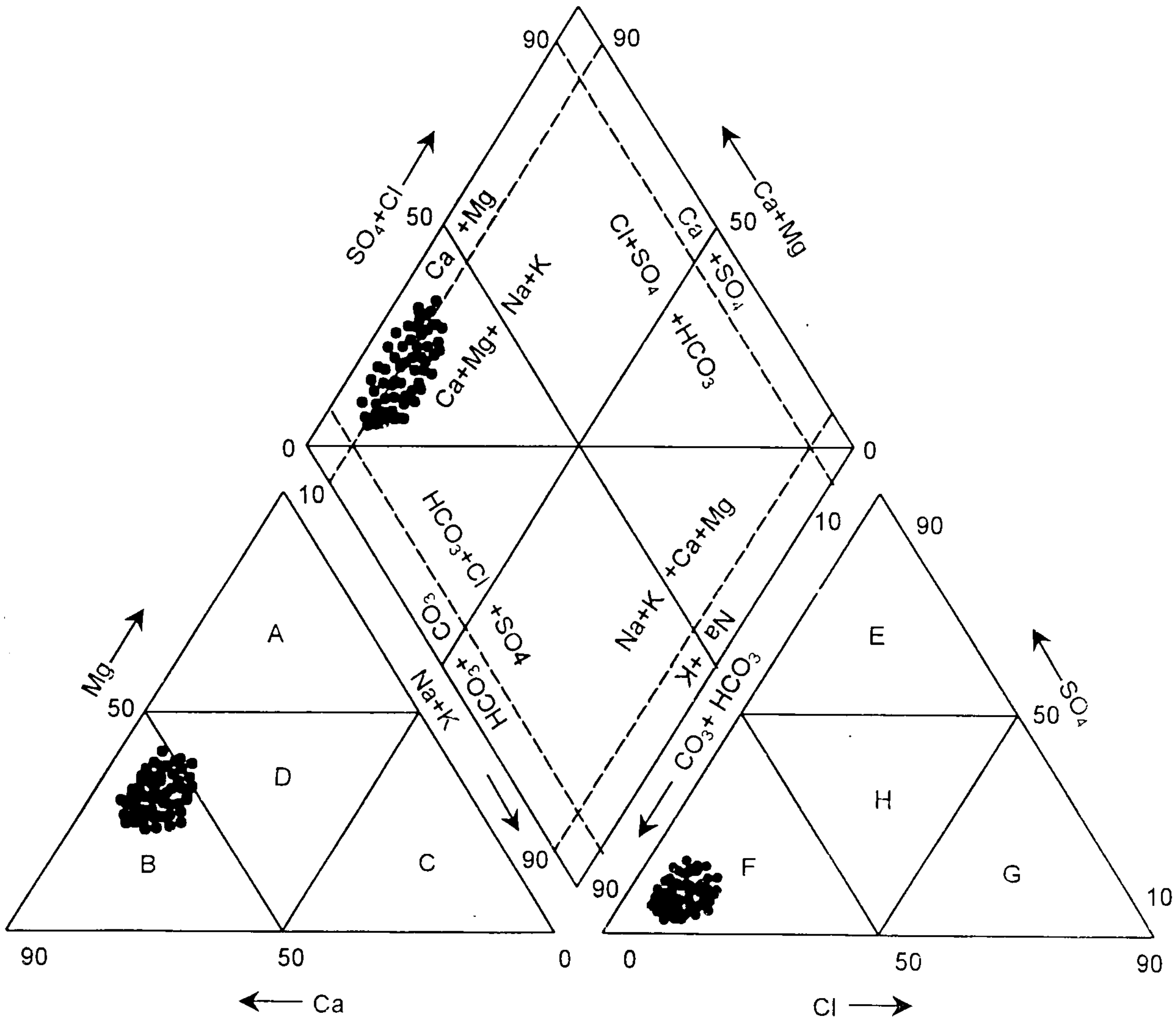
Following two chemical facies were identified using Piper trilinear diagram:

a) Ca^{++} rich bicarbonate waters / Ca- HCO_3 type (Ca $\geq$ Mg).

b) Hybrid waters / Ca-Mg- HCO_3 type (Ca $\approx$Mg).

More than 70% of the samples analyzed are Ca rich bicarbonate waters, while the remaining are Ca- Mg-bicarbonate waters. This is consistent with the fact that the meteoric waters are characteristically Ca-Mg-HCO_3 type. The geology of the catchment area, which is dominated by the presence of carbonate rocks and volcanics also favours the intake of Ca^{++} and Mg^{++} due to interaction of meteoric water or melt water with the lithology.

Fig. 5.7 Piper Trilinear diagram showing the chemical character of Dal Lake Water.



Cations Facies
A. Magnesium type
B. Calcium type
C. Sodium or Potassium type
D. No Dominant type

Anions Facies
E. Sulphate type
F. Bicarbonate type
G. Chloride type
H. No Dominant type

It is interesting to note that the mixed waters are practically confined within a few samples of Hazratbal and Boddal basins whereas Ca- bicarbonate waters occur throughout the water samples of the lake. The almost uniform chemical composition of the Dal lake points to the role of rock – water interaction within the catchment area, as the main inflow of water is from Talbal nala. The water in the Talbal nala is mainly the glacial melt derived from nearby mountain glaciers towards the NW Himalaya with some contribution of ground water in the form of springs. In simple language we can say that the chemical constituents present within water are derived from the glacial melt, surface soil and rocks, and subsurface lithology. The data plotted do not show appreciable changes, because the samples were analyzed in a year during which there was lesser precipitation that leads to a drought in the area. Consequently lesser fluctuation in the inflow of water to the lake leads to the almost uniform chemistry (major ions) throughout the year.

5.3.2 Chemical weathering of drainage basin

The source of major ions in Dal lake waters can be defined in accordance to the variation of the weight ratios of Na / (Na + Ca) as a function of TDS (Gibbs, 1970).

As TDS ranges from 200mg/l to 300 mg/l and weight ratio of Na / (Na + Ca) ranges from 0.1 to 0.3 which shows that the Dal Lake waters are categorized as rock dominance suggesting that the major mechanism controlling the water chemistry of the Dal Lake is the chemical weathering of the rock forming minerals. Ca^{++} and Mg^{++} constitute > 80% of the total cations where as the HCO_3^- constitute > 70% of total anions. HCO_3^-, Ca^{++} and Mg^{++} in the waters are almost entirely derived from rock weathering. The major portion of the ions is derived from the weathering of limestone and calcium magnesium silicates chiefly plagioclase, pyroxene and biotite. To work out the possible liganding between cations and anions (Ca + Mg) versus total cations (Fig. 5.8a), (Na + K) versus total cations (Fig. 5.8b), (Ca + Mg) versus SO_4 + HCO_3 (Fig. 5.9a) and (Ca + Mg) versus HCO_3 (Fig. 5.9b) have been plotted and suggest a better correlation. The plots of Ca + Mg versus HCO_3 + SO_4 and (Ca + Mg) versus HCO_3 shows that most of the points approach the theoretical 1:1 trend, reflecting the derivation of cations from weathering of silicates and input of HCO_3 from weathering of carbonates. Further the plot of (Ca + Mg) versus total cations shows that most of the points fall below the 1:1 trend reflecting an increasing contribution of Na and K as TDS increases. Triangular plots are also useful in assessing relative abundance of ionic species and their tendencies of liganding. In the triangular plots for the major cations (Fig. 5.10a), the data concentrate towards the Ca – Mg side reflecting the predominance of Ca and Mg and shows some what uniform values of Ca and Mg throughout the lake. The scatter of the data towards the HCO_3 end of ternary anions plot (Fig. 5.10b) shows the predominance of HCO_3, indicating the intense chemical weathering of drainage basin.

Fig. 5.8a Relationship between Ca^{++}+ Mg^{++} and TZ^{+}

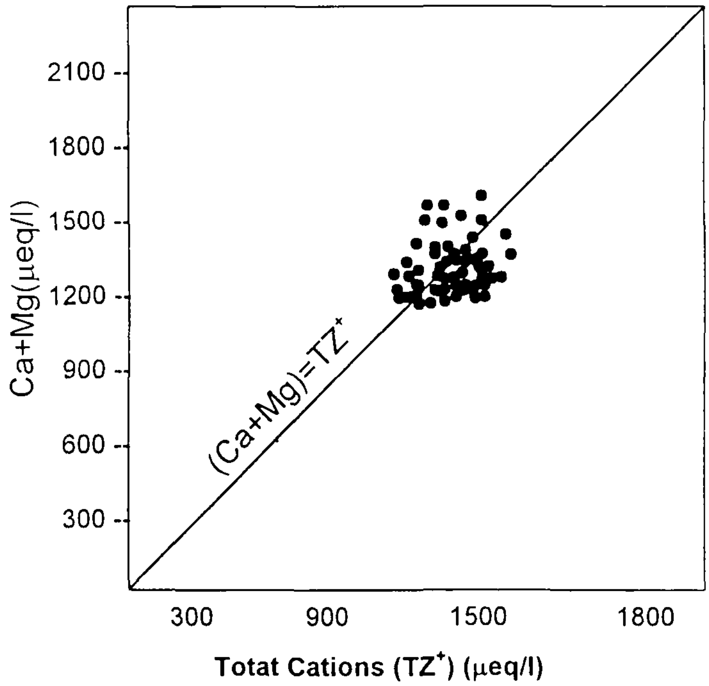
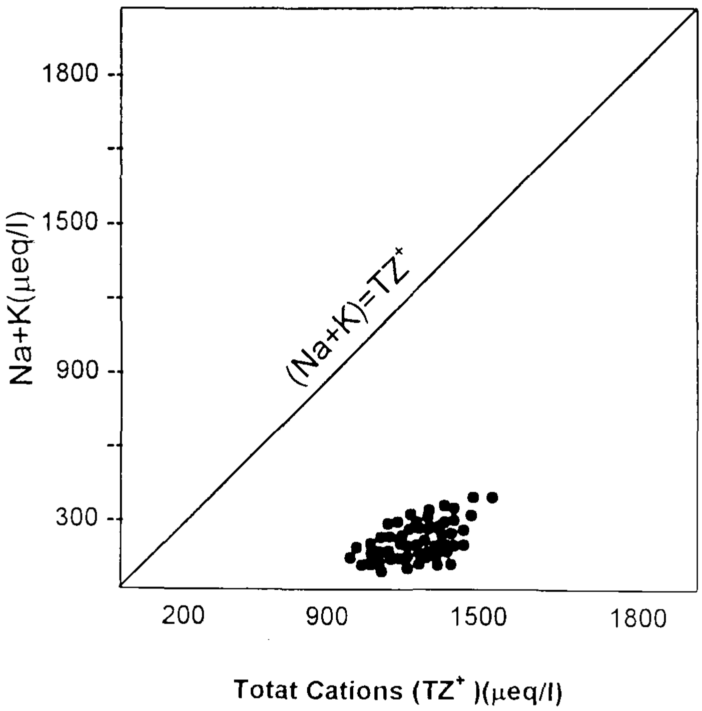


Fig. 5.8b Relationship between Na^{+}+ K^{+} and Tz^{+}



Chapter-6
Discussion

Fig. 5.9a Relationship between Ca^{++}+ Mg^{++} and SO_4^{--} +HCO_3^-

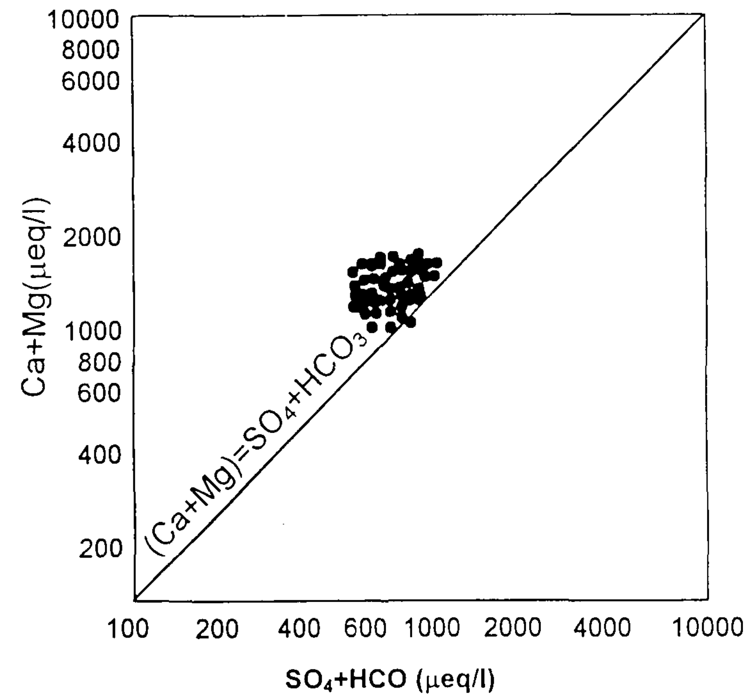


Fig. 5.9b Relationship between Ca^{++}+ Mg^{++} and HCO_3^-

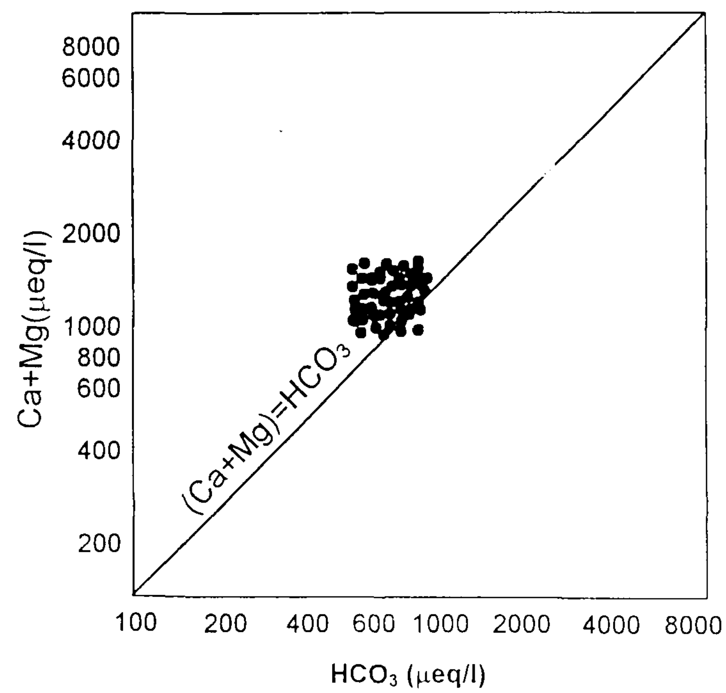


Fig.5.10a $Na^{+}+K^{+}$, Ca^{++} and Mg^{++} plot showing relative concentration of major cations.

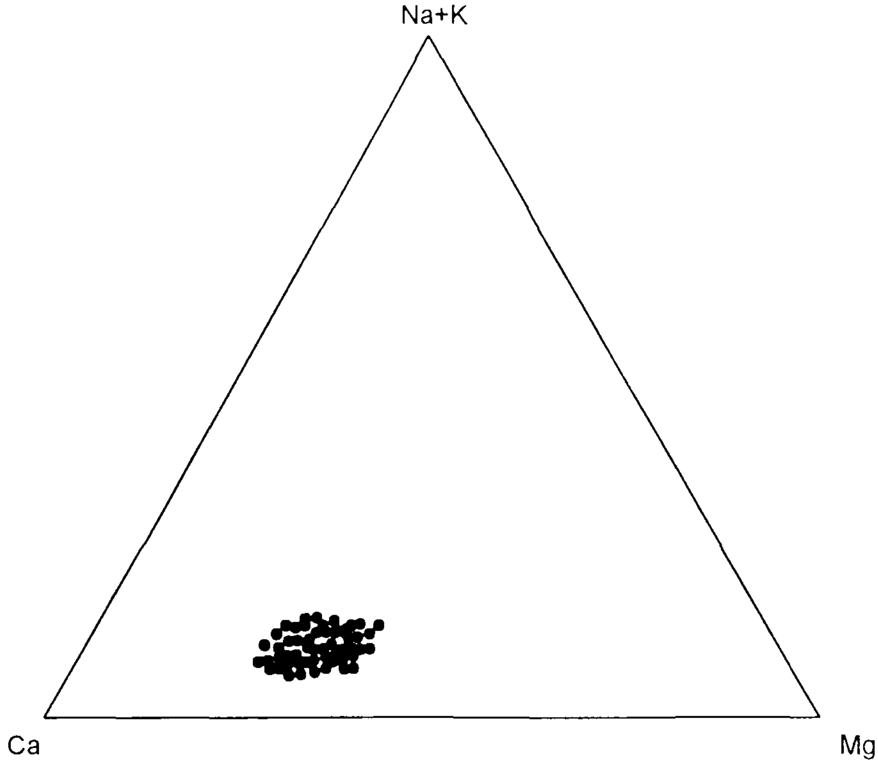
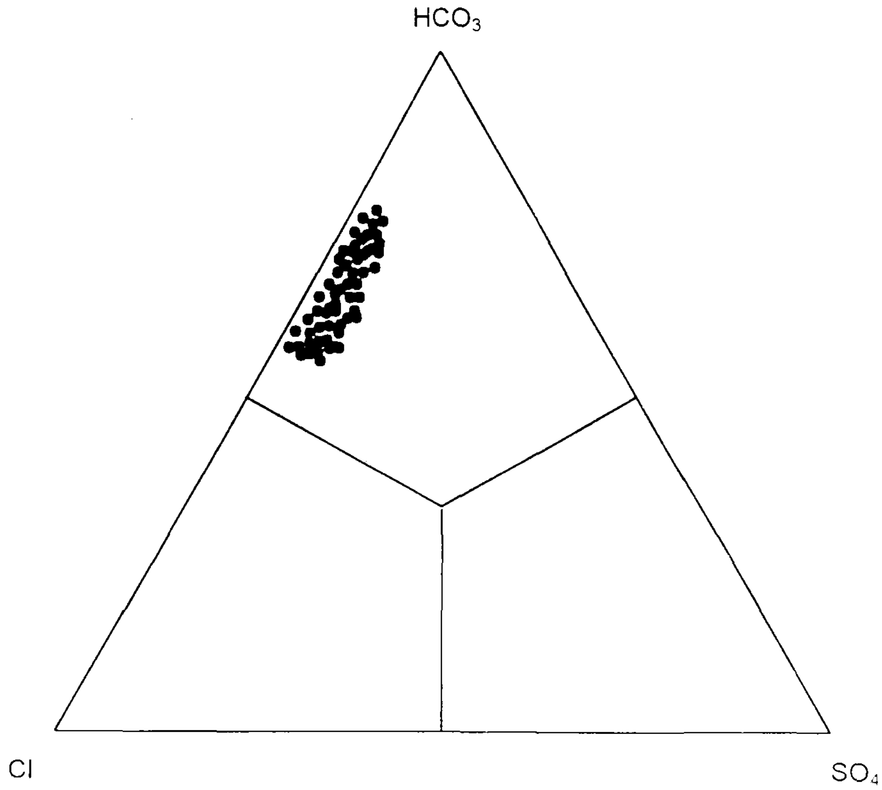


Fig.5.10b HCO_3^{-}, Cl^{-} and SO_4^{--} plot showing relative concentration of three major anions



DISCUSSION

It is not a surprise to investigate the environmental problem in Dal Lake in attempting to determine the extent of pollution in a lake by means of major and trace elemental load in sediments. The lacustrine sediments being the complex mixture of allogenic, endogenic and authogenic materials carried from different source areas, all type of chemical variations are expected in such environments. The distribution of material of different particle size in lacustrine system not only reflects the influence of the physical inputs controlling the whole system, but also. influences the chemical composition of accumulating sediments and water (Thomas 1973).

6.1 SEDIMENTS AS POLLUTION INDICATORS

6.1.1 Behavior of Major elements

The relative concentration of major elements in Dal Lake sediments (Fig. 6.1 and 6.2) shows that the Si and Al are the most dominant elements together with Ca, Mg, Fe and K constitute >70% of the total elemental composition of the sediments. Higher concentration of Si, Al and K may be due to the presence of detrital minerals like Quartz, Feldspar. etc. in the lake sediments derived from the catchment area, as these minerals are found in abundance in the rock formation of the catchment area.

Fig.6.1. Relative concentration of Si, Al, Ca and Mg in Dal Lake sediments.

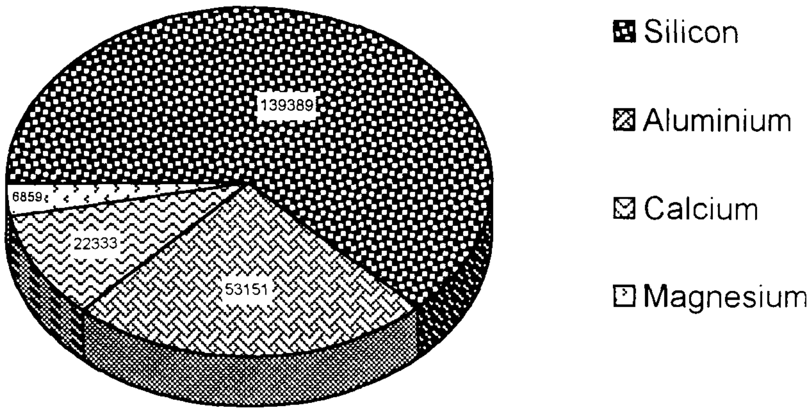


Fig.6.2. Relative concentration of Na, K, Fe, Ti Mn and P in Dal Lake sediments

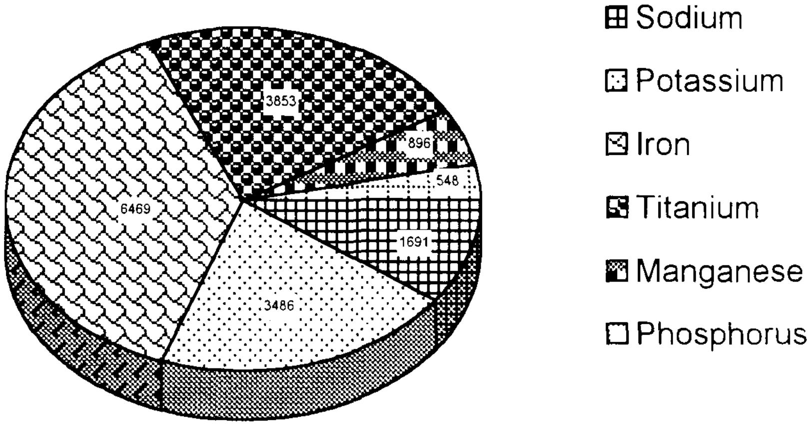
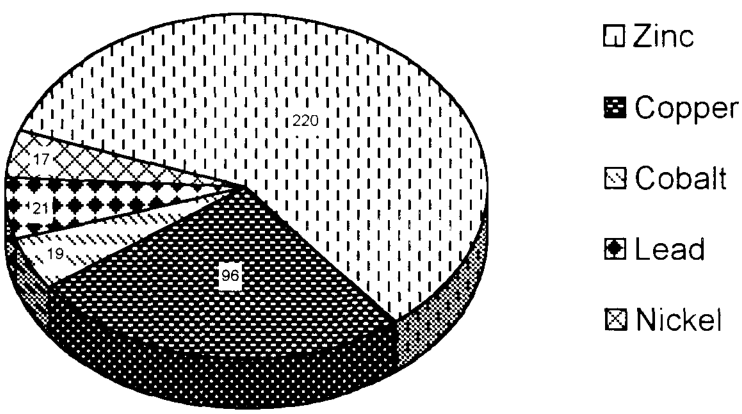


Fig.6.3. Relative concentration of Zn,Cu, Co, Pb and Ni in Dal Lake sediments



It is evident from the spatial graphical representations of inflow channel sediments already given in sediment chemistry, that almost all the sediment samples show higher degree of contamination towards the inflow channel and lower away from it. In other words the elemental contamination decreases from North to South of the lake. The expected normal trend of the major elements, Si, Al, Ca, Mg, Na, K and Fe is attributed to the weathering and dissolution of rocks of the catchment area of about 317 km^2. However, the major elements such as Ti and P show reverse trend i.e. these elements show lower concentration nearer to inflow channel and higher away from it. The reverse trend of Ti and P may be attributed to the input of sewage and other wastes. Since, the density of sewage drains and human settlement increases away from the inflow channel it reflect in the increase of Ti and P content. The Mn shows some how, abnormal behavior being higher in inflow channel (632 $\mu g/g$ to 893$\mu g/g$) and decreases away from it up to Gagribal basin, where it shows lowest concentration (594 $\mu g/g$ to 903 $\mu g/g$) and then it increases in Nagin basin where it attains its highest concentration (1032 $\mu g/g$ to 1197 $\mu g/g$) (Table 4.3). This normal trend is expected and is attributed to the rock weathering. However, the highest concentration in Nagin basin needs some additional source which can be due to the decaying of plants as the Nagin basin contains meadows of subsurface plants and the decayed plants contain more magnesium (Matthess 1982).

The seasonal variation of major elements is very interesting in that they show heterogeneous and anisotropic distributional pattern. Si and Al being high in summer (120094 μg/g and 50739 μg/g) and low in winter (94656 μg/g and 46531μg/g) (Table 4.4) shows normal seasonal behavior reflecting that these elements are mainly derived from weathering of rocks from denuded catchement area, due to high inflow of water in summer. On the other hand Ca and Mg show quite abnormal distribution being high in winter (15923 μg/g and 11029 μg/g) and low in summer (9293 μg/g and 6206 μg/g) (Table 4.4), such trend may be due to their high mobility, dilution and intake by plants, as Ca is an important plant nutrient used in various metabolic activities. Higher concentration of P in summer (612 μg/g) again depicts high anthropogenic activities, like use of fertilizers and waste material influx from human settlements and heavy tourist pressure during summer. Unlike other major elements, K shows different seasonal behavior, being high in autumn (4297 μg/g) and low in spring (2451 μg/g). The autumnal increase is attributed to the fact that K is immobile and is adsorbed by the clay particles as the clay proportion is more in autumn season due to the diminishing of hydraulic flow that causes the settlement of fine particles. Na shows positive correlation with K indicating same seasonal fluctuation.

The higher concentration of P will increase the eutrophication level of lake and its remedial measures are to minimize the use of fertilizer and other P bearing solid wastes.

6.1.2 Behavior of trace elements

The dominance of clay minerals and fine grained nature of sediments are probably responsible for the high heavy metal concentration in the sediments of Dal Lake. Relative concentration of the heavy metals (Fig 6.3) shows that Zn is dominant heavy metal followed by Cu, Pb, Co and Ni. In general the concentration of these heavy metals increases away from inflow channel being lower at inflow channel / Hazratbal basin and higher in Gagribal basin / Nagin basin (spatial variation graphs shown in sediment chemistry). The higher values recorded at different sites are close to sewer drains, house boats, restaurants, etc, reflecting their source from anthropogenic activities. The heavy metals in the Dal Lake sediments also show the simple and normal seasonal variation being higher in summer and lower in winter which is due to the input of wastes by high tourist pressure and other anthropogenic activities during summer as people prefer to stay in restaurants and house boats close to the Dal Lake during this season to protect themselves from hot temperature and to enjoy the charming summer days within the Dal Lake. Though only exception is of Nickel which shows different spatial and seasonal distribution being homogeneously distributed through out the lake body reflecting a detrital source.

It is a normal routine of primary importance to establish the natural level of these metals. Nonthless, the degree of pollution of an area can be estimated by comparison of the obtained heavy metal contents with those considered to represent the pre-civilizational level (Irabien, Velasco 1999). Many others prefer to express the metal contamination with respect to average shale to quantify the degree of pollution (Forstner and Müller, 1973; Hasnain, 1999). Concentration above these reference values are presumed to be anthropogenically affected. In this work we have used average shale composition proposed by Turekin and Wedepohl (1961) because metal contents in fossil argillaceous sediments are a global standard in general use (Muller 1979). Comparison of the metal ratio with respect to average shale for Dal Lake sediments is given in (Table 6.1) which indicate that almost all the ratios are > 1, indicating higher degree of pollution. As already discussed in sediment chemistry that the heavy metals show higher concentration at sites close to sewage drains, houseboats, restaurants and human settlements which is attributed to the fact that most of the heavy metals are released from anthropogenic sources which include motor vehicles and domestic sewage, human wastes from houseboats and restaurants, etc. In urban areas the sewer drains and storm water runoff often accelerate the transport of nutrients and other pollutants to the Dal Lake. Besides some major elements (P and Ti) show positive correlation with the heavy metal pollution indicators, reflected the same source of anthropogenic origin.

Table 6.1 Comparison of Trace metal concentration of Dal Lake sediments with global standards (μg/g).

Element	Inflow channel	Hazratbal basin	Boddal basin	Gagribal basin	Nagin basin	Shale*
Zn	165	197	223	259	250	95
Cu	96	76	82	104	89	45
Co	15	17	24	20	19	20
Pb	16	19	21	25	24	20
Ni	14	16	16	18	17	90

*Turkin and Wedepohl (1961).

6.2 HYDROLOGICAL POLLUTION ASSESSMENT

The hydrochemistry of Dal Lake (Table 5.1 and 5.2) shows the range and average concentration of various parameters measured in the spring, summer, autumn and winter seasons at the four basins i.e. Hazratbal, Boddal, Gagribal and Nagin. The surface water temperature shows slight spatial variation being comparatively higher at Gagribal basin (27.8^{0}C) and lower at Hazratbal basin (27.0^{0}C) near inflow channel. Such slight increase in water temperature at Gagribal basin seems to be due to the influx of sewage waters from domestic sources and the lower temperature at Hazratbal basin near inflow channel may be due to continuous inflow of glacial melt waters on the northern side of Dal Lake through the major feeding channels. Whereas, seasonal temperature variation shows quite distinct fluctuation, being higher in spring (11.0 ^{0}C), peaked in summer (27.7 ^{0}C) and aecrease gradually in autumn (23.0 ^{0}C) till it reaches its minimum in winter (0.9 ^{0}C). Such simultaneous fluctuations in accordance with the atmospheric temperature depict the positive correlation between the two as the surface water temperature tends to equilibrate with the atmospheric temperature. It strengthens the concept that temperature of most natural waters is the resultant heat exchange on the earths surface under the control of incoming and outgoing radiat'ons. In other words we can say that surface water temperature is mainly controlled by atmospheric temperature and therefore according to Matthess views, Dal Lake is of radiation type (Matthess, 1982). Like other fresh waters of Kashmir Valley, Dal Lake is alkaline in nature, the higher pH values recorded at Hazratbal (8.8) and Boddal (8.9) basins may be due to dissolution of carbonate rocks in the catchment area, which is also supported by the higher concentration of bicarbonates at these basins. The lesser pH values recorded at Gagribal and Nagin may be due to the input of sewage waters which are mostly acidic in nature. Spatial investigation of TDS and EC (Table 5.1) shows higher values (269 mg/l) and 420 μs/cm at Gagribal and lower values (200mg/l and 312 μs/cm at Hazratbal basin respectively, which is unexpected in normal conditions as Hazratbal basin being situated close to the major feeding channels that drains the whole catchment area and shed down the maximum sediment load in the Hazratbal basin. Instead of this Gagribal basin shows peak values which point out the possibility of maximum water contamination due to the domestic sewage waste solids and fertilizers used, rather than because of chemical weathering of drainage basin. Temporal variations shows higher concentration of TDS and EC during (246mg/l and 384 μs/cm) winter and lower during summer (220 mg/l and 344μs/cm) whereas spring and autumn recorded intermediate values (Table 5.2). This increase in ionic strength of the lake water during winter season is probably due to less dilution during the periods of low water levels and due to decomposition of aquatic plants and animals which release abundant nutrients. Whereas, low concentration in summer is attributed to the high dilution and intake of ions by plants during this growing season. In general, dissolved oxygen level, being inversely related to the thermal cycle of Dal Lake, showing lower concentration (5.3 mg/l) in summer and higher concentration (10.5 mg/l) in winter. This low DO content in summer is in consonance with the growth and abundance of aquatic plants during this season; however the high DO in winter may be as a result of low temperature and less biological activity (Vass *et al.,* 1977). Relative variation of major ions (Fig. 6.4 and 6.5) in Dal Lake water depicts the predominance of Ca and HCO_3 over the other ions and therefore the usual ionic progression is $HCO_3^- > Ca^{++} > Cl^- > Mg^{++} > Na^+ > K^+$, brings it close to the well known sequence for global fresh waters (Rodhe, 1949).

Fig.6.4 Relative concentration of Ca^{++},Mg^{++}, Na^{+} and K^{+} in Dal Lake water.

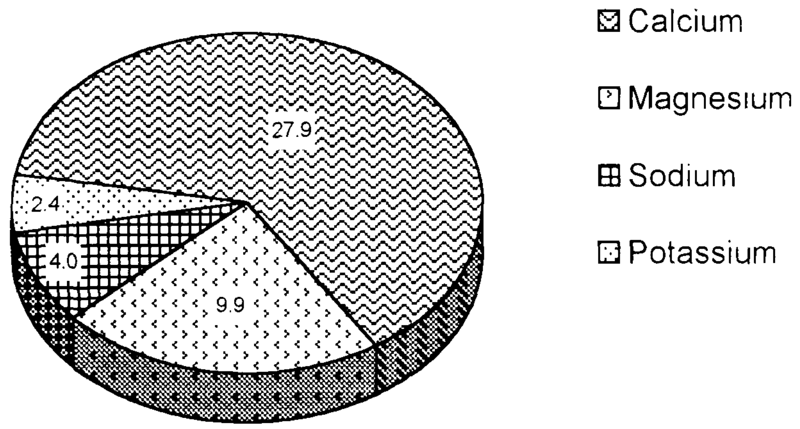


Fig.6.5 Relative concentration of HCO_3^-,Cl^-,SO_4^{--} and NO_3^- in Dal Lake water.

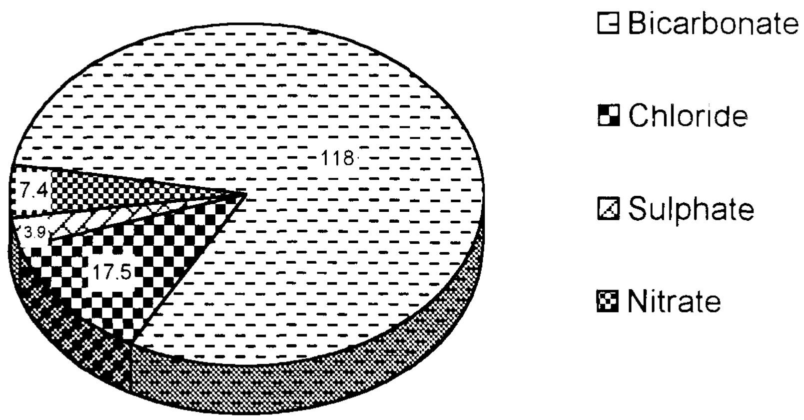
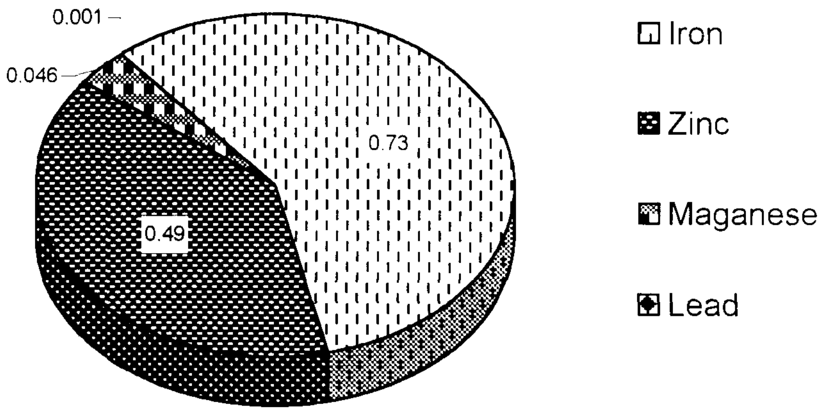


Fig.6.6 Relative concentration of Fe, Zn, Mn, and Pb in Dal Lake water.



The order of cations is $Ca^{++} > Mg^{++} > Na^{+} > K^{+}$ and the order of anions is $HCO_3^- > Cl^- > SO_4^{--}$. The higher concentration of Ca^{++} and HCO_3^- indicate that water has retained the chemical character of meteoric waters with some increasing concentration as Ca^{++} and HCO_3^- are higher in rain water /snow melt. The higher concentration of Ca^{++} and HCO_3^- indicates the intense chemical weathering of denuded catchment area, as the catchment area of the Dal Lake comprises mainly of carbonate and volcanic rocks. The interaction of these carbonate rocks with the carbonic acids, which is formed due to the reaction of CO_2 with meteoric water, liberates abundance of HCO_3^- ions and some HCO_3 which may also be released due to the dissolution of the Volcanic rocks, as the main composition of Volcanic rocks is of andesite range. On the other side, the dissolution of carbonate minerals like calcite, andesine-labradorite may release Ca^{++} ions, resulting in the higher concentration of Ca^{++} in the lake water. Hence, according to classification of the lakes developed by Ohle, (1934), Dal Lake would fall within the category of Ca rich waters. Similarly, the chemical weathering of minerals like dolomite, pyroxene and olivine may release Mg^{++} ions but it occurs in lower concentration compared to Ca^{++}, this low concentration may be due its low geo-chemical abundance. Seasonal variation graphs of hydrochemistry also shows lower Mg^{++} concentration in summer (5.4 mg/l) which is possibly due to its uptake by the aquatic plants in the formation of chlorophyll-magnesium-porphyrin metal complex and in enzymatic transformation (Wetzel, 1975). Low Na^+ and K^+ content also show their lithological origin, Na^+ fluctuates irregularly while the K^+ showed a definite regularity in its seasonal and spatial distributional pattern, which may be attributed to its low geochemical mobility. The high Cl^- content is normally expected probably due to the dissolution of common salts and may be attributed to the presence of large amount of organic matter of both allochthonous and autochthonous origin. Thresh *et al.* (1994) related it to organic pollution of animal origin. The higher SO_4^{--} concentration may be due to the association of gypsum/ anhydrite with the lacustrine deposits (Karewas) and some part of SO_4^{--} may come from agricultural sources as ZnS is widely used as fertilizer in paddy fields and floating gardens etc. NO_3 concentration shows reverse correlation with all the major ions as its highest concentration is recorded in Gagribal basin instead of Hazratbal basin. The higher values of NO_3^- at Gagribal and Nagin basin are a warning and an alarming signal of water pollution as the values approach up to 13.9 mg/l (Appendix-II). As already mentioned, the Gagribal basin being situated at southern end of the Dal Lake is surrounded by a dense populated area and is fed by number of waste water drains, besides the house-boats, and restaurants where the tourist pressure during summer is very high. The increase of NO_3^- concentration during summer may also be due to the input of fertilizer added to parts of catchment area under agriculture and the floating gardens within the lake as soil amendments.

Tempo-spatial variation of trace elements already given in hydrochemistry does not show marked differences. Slight higher trace element contamination is noticed during summer near Gagribal basin sites close to house-boats, sewage drains and restaurants reflecting the source of anthropogenic activities as a result of high tourist influx and agricultural practices during the summer season. Relative concentration of trace elements (Fig. 6.6) shows slightly higher concentration of Fe> Zn> Mn> Pb in a decreasing order. In general, lower concentration of trace elements in water samples may be attributed to the high pH, organic matter and dissolved oxygen as has been reported by Hutchinson (1957), further more, the very low or negligible concentration of trace elements in water is perhaps also as a result of their lockup in the lake sediments (Allen, 1979 and Shepard *et al.* 1980).

Seasonal variation graphs of hydrochemistry show the note worthy feature of Dal Lake waters that low concentration of most of the ionic constituents are recorded in summer (post-melting season) and high in winter (pre-melting season), which reveals that such changes in the ionic concentration of lake water are not only because of domestic and biomass activities within the lake ecosystem but are also largely governed by the contribution of snow melt waters from the whole catchment area. It infiltrates in the lake through numerous pyramid of inflow channels and enhance the dilution of ionic components during summer. It results in low ionic concentration whereas in winter the whole catchment area remain frozen and due to the resultant lack of infiltration, ionic components tend to depict an apparent concentration. Similarly, spatial variation graphs also shows another characteristic feature of Dal Lake water that these elements have higher concentration at northern side (Hazratbal basin) of lake near major inflow channels which seems to be the result of heavy sediment deposition and their interaction with water. Whereas, on moving towards southern side away from inflow channels the ionic concentration gradually decreases which seems to be due to reduction in sediment deposition and due to the consumption of some major ions by aquatic plants. It infers that sediments derived from defused catchment area by various inflow channels not only contaminate the lake water but are primarily responsible for the deterioration and evolution of Dal Lake. Inspite of this fact some pollution indicators show higher concentration in the south side (Gagribal basin) of Dal Lake near Nehru park, which indicates that waste products from house-boats, restaurants, human settlements and by tourist influx are other main sources of pollution of Dal Lake.

Summary and Conclusion

SUMMARY AND CONCLUSION

A major emphasis to the study of lakes and their deposits have undoubtedly been their potential ecological and economical importance as the lakes, being sensitive to climate and geomorphological conditions of the catchment area. Thus both the relief of the drainage area and the lake basin remains always under constant alteration by exogenic forces like weathering, erosion, transport and deposition. As a result lake sediments, are basic geo-indicators of paleoclimate and provide an elusive but rich information about the components of the entire drainage basin. Lacustrine sediments at the water column play an important role in the pollution scheme of the lake ecosystem as they are less susceptible to flow conditions and when the heavy effluent loaded waters enter the lake body, various physico-chemical reactions take place and a large portion of effluents either settles down or are adsorbed by the sediments. The presence of lacustrine Karewa deposits within the Kashmir valley reveals that the whole Valley was once a glacial lake, which found its outlet due to over spilling at Baramula few million years ago and drained.

The Kashmir Valley lies in north west Himalaya, constituting the most important segment of the Himalayan mountain range, had gone through all the episodes of the Himalayan Orogeny, besides witnessing various geological changes and the large-scale glaciation in Pleistocene periods, which resulted in the formation of lakes, wetlands and ponds in the valley.

Mostly Valley lakes occur all along the floodplains of the river Jhelum, the only recipient of the whole drainage of the Valley through the alluvium of its own deposition and covers a distance of 144 km from Verinag spring to Baramula. Most of the valley lakes are fed by melt waters from glacial lakes of the Himalaya including Dal Lake, which is the urban valley lake of fluviatile origin, being situated in the heart of the Kashmir valley on the south west of the state summer capital Srinagar. It is a small shallow lake, which has been the centre of Kashmiri civilization and plays an important role in the economy of the valley. The total open water surface area of the lake is about 11.45 Km^2 comprising Hazratbal, Boddal, Gagribal, and Nigin basins. The lake area extending from Kotarkhana to Nishat bund constitutes the largest basin (Boddal basin) of the lake, whereas the smallest and deepest basin is the Nagin basin. Hazratbal basin which is located in the north of the Dal Lake is fed by various inflow channels mainly Telbal Nalla which drains the whole catchment area and deposits more than 60% of the sediment load in the lake.

Knowledge of sediment texture is one of the efficient tools to differentiate various depositional environments of ancient as well as recent sediments. In the present study area the sediment texture of the whole inflow channel showed very high proportion of silt (63.71 %), moderate proportion of clay (24.25%) and very low proportion of sand (12.13%) (Fig. 4.3a) and the sediments of Hazratbal basin over all recorded 23.35% sand, 55.87% silt and 20.77% clay (Fig. 4.3b) The grain size distribution of the Boddal basin showed some similarity with the inflow channel, with sand, silt and clay constituting 9.97%, 63.75% and 26.27% respectively (Fig. 4.3c). However, the particle size distributional pattern of sediment grains of Gagribal basin showed some degree of similarity with that of Hazratbal basin as the sand silt and clay were recorded in a ratio of 21.82 : 63.30:14.87. (Fig. 4.3d) and the Nagin basin like inflow channel recorded high proportion of silt (66.7%), moderate proportion of clay (21.0%) and very low proportion of sand (12.5%) (Fig. 4.3e).

Overall the grain size values of the lake sediments vary from 3.2ϕ to 4.6ϕ (Table 4.1). The highest values (4.3ϕ to 4.6ϕ) are recorded in inflow channel while the lowest values (3.2ϕ to 3.6ϕ) are recorded in Gagribal basin. In the rest of the basins of the Dal Lake the mean grain size is around 4.0ϕ. Standard deviation values in the sediments of Dal Lake ranged from 1.9 ϕ to 3.0ϕ (Table 4.1), higher values being conspicuous from the Hazratbal basin and lower values from inflow channel and the rest of the basins i.e., Boddal, Gagribal and Nagin basin showed moderate values of standard deviation. It is clear from the values of standard deviation that all the sediments collected from the different basins are poorly sorted. The poorly sorted nature of the sediments is apparently due to the mixing of the modern sediments with relict sediments in the complex hydrological flow system of Dal Lake.

Skewness values (SK_1) in the sediments of Dal Lake varied between – 0.29ϕ to - 0.04ϕ (Table 4.1). The sediments are grouped into near symmetrical with skewness values of around – 0.07ϕ to – 0.04ϕ recorded from Hazratbal and Gagribal basins and coarse skewed with skewness values from -.0.29ϕ to -.0.12ϕ recorded from Boddal, Nagin and inflow channel. The coarsely skewed sediments have developed relatively under high energic condition areas near the mouths of the inflow streams while near symmetrically skewed sediments have developed under relatively low energic conditions. The kurtosis (KG) values in lake sediments ranged from 0.73 ϕ to 1.3ϕ, the Hazratbal and Gagribal basin sediments exhibit platykurtic nature where as the inflow channel Boddal and Nagin basin sediments showed leptokurtic nature which indicates the high silt deposition by the inflow channel. The binary plots between skewness and standard deviation, skewness and kurtosis and standard deviation and kurtosis shows some significant trends (Fig. 4.3 d.e.f.), the plot between skewness and standard deviation show a trend in which sorting of the sediments deteriorates with increase in skewness values. Whereas in the standard deviation and kurtosis plot most of the samples concentrate within a narrow field and the kurtosis of the sediment tend to become leptokurtic with a decrease in the standard deviation values while the sediments show normal kurtosis towards the negative end in the SK-KG plot.

The chemical nature and behaviour of various chemical constituents in lacustrine environment mainly depends upon the geology of the catchment area, soil type, anthropogenic inputs and other sediment water interactions.

The relative concentration of major elements in Dal Lake sediments (Fig. 6.1 and 6.2) shows that silicon and aluminium are the most dominant elements and along with calcium, magnesium, iron and potassium constitute more than 70% of the total elemental composition of the sediments. Higher concentration of silicon, aluminium and potassium may be due to the presence of detrital minerals like Quartz and Feldspar etc, in the lake sediments. Spatial variation of major elements of the inflow channel sediments reveals that almost all the sediment samples show higher degree of contamination towards the inflow channel and lower away from it. However, major elements such as titanium and phosphorus show reverse trend. The reverse trend of titanium and phosphorus can be attributed to the input of sewage and other wastes as the density of sewage drains and human settlements increases away from the inflow channel. The manganese shows some how, abnormal behavior being higher in inflow channel (632 μg/g to 893μg/g) and decreases away from it up to Gagribal basin, where it shows lowest concentration (594 μg/g to 903 μg/g) and then it increases in Nagin basin where it attains its highest concentration (1032 μg/g to 1197 μg/g) (Table 4.3). The highest concentration of manganese in Nagin basin needs some additional source which can be due to the decaying of plants as the Nagin basin contains meadows of subsurface plants and the decayed aquatic plants releases much magnesium.

The seasonal variation of major elements is very interesting as they show heterogeneous and anisotropic distributional pattern. Silicon and Aluminium being high in summer (120094 μg/g and 50739 μg/g) and low in winter (94656 μg/g and 46531μg/g) (Table 4.4) shows normal seasonal behavior reflecting that these elements are mainly derived from weathering of rocks from denuded catchement area (Plate Ia), due to high inflow of water in summer. On the other hand calcium and magnesium show quite abnormal distribution being high in winter (15923 μg/g and 11029 μg/g) and low in summer (9293 μg/g and 6206 μg/g) respectively (Table 4.4), such a trend may be due to their high mobility, dilution and intake by plants, as calcium is an important plant nutrient used in various metabolic activities. Higher concentration of phosphorus in summer (612 μg/g) again depicts high anthropogenic activities, like use of fertilizers and waste material influx from human settlements and heavy tourist pressure during summer. Unlike other major elements, potassium shows different seasonal behavior, being high in autumn (4297 μg/g) and low in spring (2451 μg/g). The autumnal increase is attributed to the fact that potassium is immobile and is adsorbed by the clay particles, as the clay proportion is more in autumn due to the diminishing of hydraulic flow that causes the settlement of fine particles.

Relative concentration of the heavy metals (Fig 6.3) shows that zinc is dominant heavy metal followed by copper, lead, cobalt and nickel. In general the concentration of these heavy metals increases away from inflow channels being lower at inflow channel / Hazratbal basin and higher in Gagribal basin / Nagin basin. The higher values recorded at different sites are close to sewer drains, house boats, restaurants etc, reflecting their source from anthropogenic activities. Though only exception is of Nickel which shows different spatial and seasonal distribution being homogeneously distributed through out the lake body reflecting a detrital source.

In the present study to quantify the extent of pollution and its sources we have used average shale composition proposed by Turekin and Wedepohl (1961) because metal contents in fossil argillaceous sediments are a global standard in general use. Comparison of the metal ratio with respect to average shale for Dal Lake sediments is given in Table 6.1 which indicates that almost all the ratios are more than 1 indicating higher degree of pollution. As already discussed the heavy metals show higher concentration at sites close to sewage drains, houseboats, restaurants and human settlements which is attributed to the fact that most of the heavy metals are released from anthropogenic sources which include motor vehicles and domestic sewage, human wastes from houseboats and restaurants etc. In urban areas the sewer drains and storm water runoff often accelerate the transport of the nutrients and other pollutants to the Dal Lake. Besides some major elements (phosphorus and titanium) showing positive correlation with the heavy metal pollution indicators reflected the same source of anthropogenic origin.

The hydrochemistry of Dal Lake reveals that the surface water temperature shows slight spatial variation being comparatively higher at Gagribal basin (27.8^{0}C) and lower at Hazratbal basin (27.0^{0}C) near inflow channel. Slight increase in water temperature at Gagribal basin seems to be due to the influx of sewage waters from domestic sources and the lower temperature at Hazratbal basin near inflow channel may be due to continuous inflow of glacial melt waters on the northern side of the Dal Lake through major feeding channels. Whereas seasonal temperature variation shows quite distinct fluctuation, being higher in spring (11.0 ^{0}C), peaked in summer (27.7 ^{0}C) and decreasing gradually in autumn (23.0 ^{0}C) till it reaches its minimum in winter (0.9 ^{0}C). Such simultaneous fluctuation in accordance to the atmospheric temperature depicts a positive correlation between the two as the surface water temperature tends to equilibrate with the atmospheric temperature. Like other fresh waters of Kashmir Valley, Dal Lake is alkaline in nature. Higher Ph values recorded at Hazratbal (8.8) and Boddal (8.9) basins may be due to dissolution of carbonate rocks in the catchment area and the lesser pH values recorded at Gagribal and Nagin may be due to the input of sewage waters which are mostly acidic in nature. Spatial investigation of total dissolved solids and electric conductivity shows higher values (269 mg/l) and 420 μs/cm at Gagribal and lower values (200mg/l and 312 μs/cm at Hazratbal basin respectively (Table 5.1), which is unexpected in normal conditions as Hazratbal basin being situated close to the major feeding channels that drains the whole catchment area and shed down the maximum sediment load in the Hazratbal basin. Instead of this Gagribal basin shows peak values which point out the possibility of maximum water contamination due to domestic sewage waste solids and fertilizers used, rather than because of chemical weathering of drainage basin. Temporal variations shows higher concentration of total dissolved solids and electric conductivity during (246 mg/l and 384 μs/cm) winter and lower during summer (220 mg/l and 344 μs/cm) (Table 5.2). This increase in ionic strength of the lake water during winter season is probably due to less dilution during the periods of low water levels and due to decomposition of aquatic plants and animals which release abundant nutrients. Whereas low concentration in summer is attributed to the high dilution and intake of ions by plants during this growing season. In general dissolved oxygen level, being inversely related to the thermal cycle of Dal Lake, shows lower concentration (5.3 mg/l) in summer and higher concentration

(10.5 mg/l) in winter. This low dissolved oxygen content in summer is in consonance with the growth and abundance of aquatic plants during this season; however the high dissolved oxygen in winter may be as a result of low temperature and less biological activity. Relative variation of major ions (Fig. 6.4 and 6.5) in Dal Lake water depicts the predominance of calcium and bicarbonate over the other ions and therefore the usual ionic progression is bicarbonate > calcium> chloride > magnesium > sodium > potassium. The higher concentration of calcium and bicarbonate indicate that water has retained the chemical character of meteoric waters with some increasing concentration as calcium and bicarbonate are higher in rain water /snow melt. The higher concentration of calcium and bicarbonate indicates the intense chemical weathering of denuded catchment area, as the catchment area of the Dal Lake comprises mainly of carbonate and volcanic rocks. Similarly the chemical weathering of minerals like dolomite, pyroxene and olivine may release magnesium ions but it occurs in lower concentration compared to calcium, this low concentration may be due its low geo-chemical abundance. Seasonal variation graphs of hydrochemistry also shows lower magnesium concentration in summer (5.4 mg/l) which is possibly due to its uptake by the aquatic plants in the formation of chlorophyll-magnesium-porphyrin metal complex and in enzymatic transformation. Low sodium and potassium content also show their lithological origin, sodium fluctuates irregularly while the potassium showed a definite regularity in its seasonal and spatial distributional pattern which may be attributed to its low geochemical mobility. The high chloride content is normally expected probably due to the dissolution of common salts and may be attributed to the presence of large amount of organic matter of both allochthonous and autochthonous origin. The higher sulphate concentration may be due to the association of gypsum/ anhydrite with the lacustrine deposits (Karewas) and some part of sulphate may come from agricultural sources. Nitrate concentration shows reverse correlation with all the major ions as its highest concentration is recorded in Gagribal basin instead of Hazratbal basin. The higher values of nitrate at Gagribal and Nagin basin is a warning and an alarming signal of water pollution as the values approach up to 13.9 mg/l (Appendix-II). As already mentioned the Gagribal basin being situated at the southern end of the Dal Lake is surrounded by dense populated area and is fed by number of waste water drains, besides the house-boats and restaurants where the tourist pressure during summer is very high. The increase of nitrate concentration during summer may also be due to use of fertilizer in parts of catchment area under agriculture and the floating gardens within the lake as soil amendments.

In Dal Lake the water types were determined on the basis of their chemical composition. The concentration of the major cation and anions obtained in the laboratory were plotted on standard Piper Trilinear diagram (Fig. 5.7)

On the basis of this diagram two chemical facies were identified.

Ca^{++} rich bicarbonate waters / Ca- HCO_3 type (Ca $\geq$ Mg) and

Hybrid waters / Ca-Mg- HCO_3 type (Ca $\approx$Mg).

More than 70% of the samples analyzed are Ca rich bicarbonate waters, while the remaining are Ca- Mg-bicarbonate waters. This is consistent with the fact that the meteoric waters are characteristically Ca-Mg-HCO_3 type.

TDS ranges from 200mg/l to 300 mg/l and weight ration of Na / (Na + Ca) ranges from 0.1 to 0.3 (Table 5.1) which shows that the Dal Lake waters are categorized as rock dominance suggesting that the major mechanism controlling the water chemistry of the Dal Lake is the chemical weathering of the rock forming minerals. The major portion of the ions is derived from the weathering of limestone and calcium magnesium silicates chiefly plagioclase, pyroxene and biotite. To work out the possible liganding between cations and anions (Ca + Mg) versus total cations (Fig. 5.8a). (Na + K) versus total cations (Fig. 5.8b), (Ca + Mg) versus SO_4 + HCO_3 (Fig. 5.9a) and (Ca + Mg) versus HCO_3 (Fig. 5.9b), have been plotted and suggest a better correlation. The plots of Ca + Mg versus HCO_3 + SO_4 and (Ca + Mg) versus HCO_3 shows that most of the points approach the theoretical 1:1 trend, reflecting the derivation of cations from weathering of silicates and input of HCO_3 from weathering of carbonates. Further the plot of (Ca + Mg) versus total cations shows that most of the points fall below the 1:1 trend reflecting and increasing contribution of Na and K as TDS increases. Triangular plots are also useful in assessing relative abundance of ionic species and their tendencies of liganding. In the triangular plots for the major cations (Fig. 5.10a) the data concentrate towards the Ca – Mg side reflecting the predominance of Ca and Mg and shows some what uniform values of Ca and Mg throughout the lake. The scatter of the data towards the HCO_3 end of ternary anions plot (Fig. 5.10b) shows the predominance of HCO_3, indicating the intense chemical weathering of drainage basin. Tempo-spatial variation of trace elements does not show marked differences, slight higher trace element contamination is noticed during summer near Gagribal basin sites close to house-boats sewage drains and restaurants reflecting the source of anthropogenic activities as a result of high tourist influx and agricultural practices during the summer season. Relative concentration of trace elements (Fig. 6.3) shows slightly higher concentration of iron> Zinc> Manganese> lead in a decreasing order.

Another noteworthy feature of the Dal Lake hydrochemistry is that lower concentration of most of the ionic constituents are recorded in summer and higher in winter, which reveals that such changes in the ionic concentration of lake water are not only because of domestic and biomass activities within the lake ecosystem but are also largely governed by the contribution of snow melt waters which infiltrates in the lake and enhance the dilution of ionic components during summer, results in low ionic concentration whereas in winter the whole catchment area remain frozen and due to the resultant lack of infiltration, ionic components tend to depict higher concentration because of less dilution. Similarly spatial variations also shows another characteristic feature of Dal Lake water that the chemical constituents have higher concentration at northern side (Hazratbal basin) of lake near major inflow channels which seems to be the result of heavy sediment deposition and their interaction with water whereas on moving away from inflow channels the ionic concentration gradually decreases which seems to be due to reduction in sediment deposition and due to the consumption of some major ions by aquatic plants. It infers that sediments derived from defused catchment area by various inflow channels not only contaminate the lake water but are primarily responsible for the deterioration and evolution of Dal Lake. Inspite of this fact some pollution indicators shows higher concentration in the southern side (Gagribal basin) of Dal Lake near Nehru park, which indicates that waste products from house-boats, restaurants, human settlements and by tourist influx are other main sources of pollution of Dal Lake.

On the basis of results and observations obtained from the present study carried out on the geomorphology, hydrochemistry and sediment geochemistry of the Dal Lake, it is concluded that the lake body has not only reduced in volume and aerial extension but its water pollution has attained high pollution magnitude and posing health hazards to the aquatic and human life. The results reveal that the main factors responsible for the deterioration and eutrophication of the lake ecosystem are:

(i) Increasing rate of sedimentation.

(ii) Higher disposal of domestic waste and agricultural run-off.

(iii) Encroachments and reclamation of huge tracts in the form of floating gardens.

As a result of these anthropogenic perturbations the lake body has shrunk over half (11.45 Km^2) of the area it was at the turn of this century (22 Km^2). The average depth has left only 2.5m, which was about 6m. It is clear that the condition of the lake has reached to that critical stage, from the hydrological and ecological point of view, when all conservative measures must be taken to save it from further deterioration. Thus it is necessary here to suggest some remedial measures for the Dal Lake restoration.

(i) Afforestation and soil conservation of catchment area.

(ii) Improvement of the settling basis on Talbal Nala.

(iii) Control of encroachments including redevelopment of floating gardens.

(iv) Solid waste management.

(v) Houseboat sanitation.

(vi) Marginal dredging, selective de-weeding and removal of Nishat bund for improving water circulation.

(vii) Improvement in regional sanitation and drainage system.

(viii) Extension of foreshore road around the lake.

(ix) Improvement of navigation routes.

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Appendices

Appendix I

a) Fluctuation of major and trace element concentration in Dal Lake sediments during spring season year 2001(μg/g)

Site	Si	Al	Ca	Mg	Na	K	Fe	Ti	Mn	P	Zn	Cu	Co	Pb	Ni
IF1	161978	72451	41865	11878	2242	4310	7935	2721	893	348	142	62	12	13	12
IF2	160957	67342	41107	11125	1825	3926	7721	2373	832	325	153	68	16	15	18
IF3	161043	68432	41625	11375	1952	4150	7769	2432	856	334	145	67	18	16	16
IF4	161537	70670	41322	11645	2134	4238	7841	2689	879	341	149	63	14	12	14
HZ1	145029	49209	10573	10237	1506	2302	6001	2872	891	439	160	72	15	19	14
HZ2	147153	52729	10827	10975	1872	2580	6315	3427	968	478	168	86	20	21	17
HZ3	146607	51281	10300	10743	1832	2409	6274	3218	939	461	162	80	22	23	15
HZ4	145774	50770	10107	10531	1691	2328	6104	2970	905	454	159	78	17	20	13
BD1	110947	48838	1307	8347	845	2158	6392	4672	810	589	223	72	19	20	18
BD2	111237	50567	1532	8562	962	2304	4564	5171	867	638	229	78	23	26	19
BD3	110800	59156	1021	8107	741	2246	4298	4356	789	567	230	79	22	25	20
BD4	109457	48439	1207	8451	894	2190	4432	4983	842	607	227	70	21	23	17
GB1	103457	42961	2218	8093	1127	1826	5903	4728	810	637	243	85	20	21	20
GB2	105972	43543	2867	8145	1226	2023	6010	5196	865	681	239	78	22	26	21
GB3	166287	46156	3178	7928	1289	2207	6152	5342	891	708	246	89	25	27	23
GB4	104197	45822	2507	7819	1178	1943	5974	4962	837	656	240	72	18	23	18
NB1	64743	39215	3263	9692	722	1581	7015	3572	1197	571	242	80	13	20	19
NB2	61490	35431	2743	9302	587	1429	6812	3167	1156	510	240	93	18	24	21
NB3	60249	34217	2572	9172	563	1328	6750	3052	1136	489	249	92	22	26	20
NB4	62978	37621	2973	9447	619	1552	7938	3347	1178	536	245	87	15	21	18

b) Fluctuation of major and trace element concentration in Dal Lake sediments during summer season year 2001(μg/g)

Site	Si	Al	Ca	Mg	Na	K	Fe	Ti	Mn	P	Zn	Cu	Co	Pb	Ni
IF1	246775	74660	40937	11076	2422	4135	9017	2593	684	370	184	70	13	17	11
IF2	244087	70723	40300	10951	2701	3818	8762	2167	618	347	189	78	15	22	14
IF3	244986	71548	40715	10987	2530	3928	8882	2215	645	352	198	75	17	20	15
IF4	245476	73298	40857	11127	2670	4052	8973	2438	670	361	192	65	14	18	13
HZ1	164631	60914	1460	8910	865	2324	6029	3192	782	553	239	85	12	20	13
HZ2	168846	63231	2157	9457	1012	2597	6407	3623	849	615	231	90	16	26	18
HZ3	167293	62915	1820	9243	932	2561	6327	3478	815	592	242	93	13	22	20
HZ4	166475	61257	1648	9157	897	2429	6211	3342	789	573	237	89	14	18	15
BD1	165342	51241	981	1367	1102	2015	4307	3867	768	687	248	82	14	25	13
BD2	167164	56934	1327	1752	1209	2155	4478	4307	820	776	257	96	18	28	16
BD3	166293	54194	749	1103	1085	1992	4266	3559	747	629	250	90	16	27	19
BD4	164523	53465	1137	1582	1129	2087	4395	4040	793	728	252	88	15	26	14
GB1	158407	51108	923	6925	1206	2406	5942	4932	821	742	289	135	27	29	14
GB2	160921	53431	1318	7451	1372	2697	6078	5481	879	796	302	193	22	24	22
GB3	162445	54235	1537	7742	1419	2815	6193	5792	903	835	309	110	26	32	16
GB4	159236	52217	1126	7247	1261	2656	5973	5289	848	768	292	90	23	26	14
NB1	124415	46404	2132	2257	792	2472	3762	4204	1178	667	282	85	19	22	16
NB2	120548	43195	1571	1972	592	2324	3467	3743	1143	612	275	82	15	31	17
NB3	119673	42635	1342	1738	568	2053	3357	3598	1125	598	297	108	24	25	14
NB4	122708	44793	1837	2082	643	2398	3649	3986	1169	643	288	91	22	23	15

c) Fluctuation of major and trace element concentration in Dal Lake sediments during autumn season year 2001(μg/g)

Site	Si	Al	Ca	Mg	Na	K	Fe	Ti	Mn	P	Zn	Cu	Co	Pb	Ni
IF1	216921	72096	42925	11823	2819	5644	9582	2487	715	362	152	60	12	11	10
IF2	215137	68431	42089	11247	2407	5407	9265	2039	632	338	167	64	14	13	13
IF3	215643	70585	42378	11547	2543	5597	9347	2318	657	351	158	63	15	14	12
IF4	216080	71627	42535	11743	2642	5532	9452	2352	682	357	162	62	13	12	11
HZ1	84096	52193	1723	10272	2037	5296	6468	2077	750	574	201	63	13	18	16
HZ2	88541	56854	2342	11527	2265	5643	6914	2745	823	561	198	70	14	24	15
HZ3	87450	54341	2149	11348	2142	5531	6693	2531	802	543	207	74	15	20	13
HZ4	86578	53437	1980	10632	2107	5327	6578	2367	780	534	203	65	12	17	14
BD1	81946	51648	890	8641	1915	4691	4957	2519	657	539	220	70	15	17	14
BD2	83847	53015	1152	8972	2037	4980	5189	2968	718	592	228	75	12	25	17
BD3	82476	52172	801	8532	1867	4582	4832	2339	625	547	232	76	14	23	16
BD4	80749	50836	1079	8715	1957	4772	5078	2676	689	565	225	72	13	19	18
GB1	73163	47462	1073	9278	1764	3073	8018	2719	598	617	239	79	18	21	15
GB2	76734	50249	1472	9721	1835	3283	8380	3075	652	636	235	92	15	25	17
GB3	77625	51652	1781	9893	1973	3420	8463	3291	683	689	246	96	16	22	20
GB4	74974	48194	1210	9527	1801	3149	8162	2928	627	629	240	88	14	20	13
NB1	62237	36964	1923	9502	1129	2659	7735	3252	1105	622	229	85	18	18	18
NB2	60642	34187	1407	9243	1021	2483	7408	2967	1067	587	219	89	17	20	17
NB3	58460	33653	1273	9083	987	2369	7322	2808	1032	558	232	90	20	19	19
NB4	61517	35781	1783	9434	1061	2507	7583	3047	1094	607	224	78	19	16	15

d) Fluctuation of major and trace element concentration in Dal Lake sediments during winter season year 2001($\mu g/g$)

Site	Si	Al	Ca	Mg	Na	K	Fe	Ti	Mn	P	Zn	Cu	Co	Pb	Ni
IF1	152092	65721	43917	12675	2389	5364	9230	2297	803	282	131	57	11	10	13
IF2	150391	61220	43097	12173	2137	5082	8913	1913	725	260	138	59	13	12	15
IF3	150932	62567	43179	12242	2255	5170	9073	2052	758	267	140	60	14	13	16
IF4	151241	64927	43487	12432	2327	5312	9176	2201	787	271	135	58	12	11	12
HZ1	102925	49156	28017	12087	1303	2708	6093	2341	763	334	152	60	14	12	14
HZ2	107451	52672	29348	12592	1527	2942	6753	2963	843	397	163	64	18	19	13
HZ3	105282	51207	28753	12352	1409	2822	6602	2617	812	374	158	68	17	17	15
HZ4	104417	49845	28341	12142	1381	2878	6512	2581	785	346	155	59	15	15	11
BD1	102376	44321	2153	8979	989	2837	4328	3226	735	432	189	67	13	16	12
BD2	105731	47341	2679	9358	1123	3145	4592	3769	784	485	192	69	17	15	18
BD3	104324	46933	1907	8768	913	2703	4292	3097	723	410	207	71	15	18	15
BD4	101540	43765	2340	9129	1018	2988	4462	3575	758	458	197	68	14	13	11
GB1	76854	38679	2371	11017	1517	2937	6407	3210	594	533	213	73	14	19	15
GB2	79463	39365	2792	11735	1691	3320	6574	3652	645	562	210	92	17	20	19
GB3	80275	40217	3042	11978	1736	3387	6702	3979	673	586	215	87	15	18	20
GB4	77342	39056	2683	11451	1572	3029	6431	3405	619	551	216	76	13	17	17
NB1	37536	35169	3118	10217	1032	2509	7118	3127	1129	461	205	69	13	21	13
NB2	34743	32914	2537	9783	867	2317	6944	2985	1087	403	203	76	15	23	14
NB3	32003	31641	2362	9631	810	2208	6735	2928	1057	371	210	89	17	25	16
NB4	36218	33619	2815	9842	979	2456	7064	3010	1108	426	206	71	14	22	15

APPENDIX II

(a) Physico –chemical characteristics of Dal Lake water during spring season in year 2001 (mg/l).

Sties	Temperature (^0C)	pH	T.D.S. mg/l	E.C. μs/cm	D.O. mg/l	Ca^{++} mg/l	Mg^{++} mg/l	Na^+ mg/l	K^+ mg/l	HCO_3^- mg/l	Cl^- mg/l	SO_4^{--} mg/l	NO_3^- mg/l	Fe mg/l	Zn mg/l	Mn mg/l	Pb mg/l	Tz^+ μeq/l	Tz^- μeq/l
HZ1	9.1	8.7	235	367	6.8	18.7	8.6	3.9	2.3	65	25.7	3.2	2.2	1.16	0.63	0.042	0.018	1.87	1.85
HZ2	7.8	8.7	236	369	8.9	16.5	7.5	3.5	1.8	62	21.3	2.6	2.0	1.05	0.47	0.038	0.012	1.64	1.67
HZ3	9.5	8.6	237	370	6.8	15.6	6.5	3.2	1.5	55	19.5	2.7	1.6	0.71	0.49	0.036	0.012	1.49	1.52
HZ4	10.2	8.6	235	367	11.2	18.9	8.7	4.0	2.4	68	26.2	3.2	2.3	1.16	0.65	0.045	0.017	1.89	1.93
HZ5	11.5	8.6	240	375	11.7	17.4	8.1	3.7	2.1	67	22.3	2.7	1.7	0.80	0.48	0.040	0.013	1.75	1.79
HZ6	9.4	8.7	239	373	5.7	13.6	6.0	2.3	1.1	50	14.7	1.9	1.4	0.47	0.14	0.034	0.008	1.30	1.27
HZ7	8.3	8.7	237	370	7.7	17.9	8.4	3.8	2.2	64	23.7	3.0	2.1	1.13	0.57	0.042	0.015	1.81	1.78
HZ8	7.4	8.7	242	378	10.2	18.3	8.5	3.7	2.1	67	24.3	3.1	2.0	1.02	0.62	0.039	0.016	1.83	1.85
HZ9	11.2	8.7	245	383	6.9	16.3	7.2	3.3	1.6	61	20.1	2.8	1.8	0.94	0.54	0.037	0.014	1.59	1.63
HZ10	15.4	8.6	247	386	9.5	18.2	8.5	3.9	2.2	68	24.1	2.9	2.3	1.18	0.58	0.046	0.014	1.83	1.85
HZ11	16.3	8.6	250	391	8.4	15.2	6.3	3.1	1.3	55	18.6	2.5	1.9	0.98	0.43	0.043	0.010	1.44	1.48
HZ12	15.7	8.6	238	372	8.9	19.1	8.8	4.1	1.8	66	27.8	3.3	2.2	1.17	0.66	0.044	0.018	1.90	1.94
HZ13	13.8	8.7	241	376	10.4	16.4	7.3	3.4	2.4	63	20.5	2.4	1.5	0.52	0.31	0.038	0.008	1.63	1.67
HZ14	14.2	8.7	242	378	11.8	14.5	6.2	3.0	1.2	54	17.8	2.3	1.6	0.69	0.26	0.043	0.009	1.39	1.43
HZ15	8.9	8.7	249	389	11.7	19.6	8.8	4.2	2.5	68	28.2	3.4	2.1	1.15	0.67	0.041	0.008	1.95	1.99
BD1	5.7	8.5	218	341	7.5	13.2	5.2	2.0	1.1	47	15.2	2.1	1.1	0.39	0.29	0.035	0.006	1.20	1.24
BD2	6.9	8.2	220	344	7.6	14.5	5.9	2.5	1.7	50	17.6	2.4	1.2	0.43	0.46	0.038	0.010	1.36	1.39

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BD3	5.3	8.3	225	351	8.2	15.2	6.0	2.8	1.9	54	18.5	2.5	2.3	0.96	0.48	0.051	0.011	1.42	1.45
BD4	7.4	8.4	231	361	8.4	12.4	4.3	1.8	1.2	43	13.7	1.7	2.1	0.93	0.12	0.048	0.002	1.08	1.12
BD5	5.3	8.3	227	355	8.7	14.2	5.8	2.6	1.6	54	14.9	2.2	1.3	0.47	0.34	0.037	0.006	1.34	1.37
BD6	5.0	8.6	230	359	8.6	13.9	5.7	2.4	1.4	52	15.8	2.0	1.1	0.37	0.26	0.039	0.004	1.30	1.35
BD7	5.4	8.5	214	334	8.9	15.1	6.1	2.8	1.9	57	17.8	2.5	2.3	0.94	0.52	0.049	0.009	1.43	1.48
BD8	7.8	8.7	222	347	7.2	16.2	6.3	3.1	2.2	59	19.7	2.3	2.1	0.92	0.38	0.045	0.008	1.52	1.57
BD9	8.9	8.6	228	356	7.3	17.6	6.7	3.4	2.3	65	20.6	2.9	2.3	0.94	0.59	0.047	0.012	1.64	1.68
BD10	10.1	8.5	221	345	7.4	15.4	6.2	3.0	2.0	56	18.9	2.4	2.2	0.94	0.50	0.046	0.008	1.46	1.49
BD11	13.0	8.3	230	359	7.5	12.7	4.4	1.9	1.3	43	14.5	1.9	1.8	0.65	0.18	0.045	0.002	1.11	1.16
BD12	12.9	8.4	235	367	8.1	14.6	6.0	2.7	1.8	55	16.9	2.3	1.4	0.52	0.39	0.043	0.007	1.39	1.42
BD13	12.6	8.5	232	362	8.5	15.5	6.2	3.1	2.1	51	19.2	2.1	2.2	0.95	0.27	0.050	0.005	1.47	1.43
BD14	11.4	8.6	234	366	7.9	17.2	6.6	3.4	2.2	62	20.3	2.7	2.1	0.89	0.57	0.044	0.012	1.60	1.65
BD15	11.7	8.7	229	358	8.8	14.1	5.8	2.5	1.5	53	16.3	2.0	1.9	0.78	0.23	0.042	0.003	1.33	1.37
GB1	9.5	7.9	230	359	8.1	15.7	6.6	3.2	1.6	58	19.1	2.3	9.2	1.18	0.37	0.052	0.009	1.51	1.54
GB2	10.8	8.1	238	372	8.5	17.4	7.5	3.6	2.1	63	23.2	2.4	9.3	1.23	0.40	0.051	0.010	1.70	1.73
GB3	11.4	8.2	236	369	8.9	14.6	6.2	2.9	1.4	52	16.5	2.0	8.9	1.13	0.23	0.047	0.006	1.40	1.37
GB4	7.8	7.6	225	351	9.2	13.2	5.3	2.1	1.2	48	15.4	1.8	7.5	0.83	0.16	0.038	0.005	1.22	1.26
GB5	7.9	7.77	221	345	9.1	15.4	6.5	3.1	1.5	59	18.3	2.1	7.8	0.73	0.26	0.037	0.007	1.48	1.53
GB6	8.7	8.3	232	362	8.8	16.7	7.3	3.4	1.8	62	21.5	2.4	7.2	0.53	0.42	0.036	0.010	1.63	1.37
GB7	12.2	9.7	240	375	7.9	17.5	7.5	3.5	2.2	64	22.7	2.9	9.6	1.29	0.65	0.053	0.013	1.70	1.75
GB8	13.4	8.5	242	378	8.0	15.5	6.4	3.0	1.4	58	17.5	1.9	7.4	0.67	0.21	0.048	0.005	1.45	1.49
GB9	12.7	7.8	245	383	8.7	16.3	7.1	3.3	1.7	60	20.2	2.3	7.9	0.85	0.39	0.046	0.009	1.58	1.61

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GB10	10.8	8.3	250	391	9.4	18.3	8.4	3.8	2.3	67	24.7	3.0	9.5	1.27	0.73	0.039	0.014	1.83	1.86
GB11	13.7	8.4	248	387	9.5	17.8	7.6	3.7	2.2	65	23.5	2.7	9.4	1.25	0.51	0.052	0.012	1.73	1.77
GB12	11.5	8.5	249	389	9.3	18.4	8.5	3.8	2.4	68	25.2	3.2	9.6	1.29	0.72	0.054	0.015	1.84	1.89
GB13	15.4	8.1	246	383	9.0	17.2	7.4	3.6	2.0	62	22.4	2.5	9.2	1.23	0.64	0.051	0.011	1.67	1.71
GB14	16	7.9	240	375	8.9	16.2	7.0	3.2	1.6	61	19.7	2.2	8.7	1.12	0.32	0.048	0.008	1.56	1.59
GB15	15.9	7.8	243	379	8.7	14.5	6.1	2.8	1.3	56	16.1	2.1	8.5	0.98	0.28	0.046	0.007	1.38	1.42
NB1	10.5	8.5	248	387	9.6	14.5	5.5	2.4	1.4	54	15.2	2.1	4.0	0.95	0.23	0.041	0.004	1.32	1.35
NB2	9.3	8.6	250	391	8.5	15.7	6.2	2.9	2.0	48	17.2	2.5	4.1	0.96	0.38	0.042	0.008	1.47	1.51
NB3	15.6	8.5	246	384	8.5	16.2	6.3	3.0	2.1	62	16.9	2.6	4.2	1.01	0.56	0.043	0.009	1.51	1.55
NB4	12.0	8.9	245	383	9.2	13.4	5.2	2.1	1.3	51	13.9	2.0	3.4	0.64	0.18	0.039	0.003	1.22	1.26
NB5	7.5	9.1	251	392	9.5	14.2	5.3	2.2	1.2	52	14.7	2.2	3.6	0.72	0.27	0.037	0.005	1.27	1.31
NB6	14.3	8.5	239	373	9.1	15.3	6.1	2.7	1.8	58	16.4	2.4	3.5	0.68	0.34	0.036	0.007	1.43	1.47
NB7	8.8	8.5	253	395	8.4	17.6	6.7	3.4	2.4	53	20.7	2.9	4.3	0.98	0.55	0.038	0.011	1.64	1.67
NB8	8.6	8.6	245	383	8.6	14.5	5.4	2.3	1.4	55	15.0	2.0	3.3	0.56	0.16	0.031	0.003	1.30	1.35
NB9	9.5	9.2	249	389	9.5	12.9	4.9	1.8	1.2	46	13.8	1.8	3.2	0.63	0.09	0.032	0.001	1.16	1.19
NB10	18.2	9.5	245	383	8.5	15.2	6.0	2.6	1.7	57	16.7	2.4	3.4	0.49	0.40	0.034	0.007	1.41	1.46
NB11	16.3	8.5	252	394	8.7	13.2	5.1	2.0	1.3	49	14.5	1.9	3.2	0.55	0.08	0.031	0.002	1.20	1.24
NB12	16.2	8.5	250	391	9.7	16.4	6.4	3.1	2.1	61	18.4	2.5	4.2	1.03	0.49	0.040	0.009	1.53	1.57
NB13	14.5	8.8	257	401	8.6	17.3	6.6	3.4	2.3	63	20.4	2.8	4.5	1.06	0.56	0.43	0.010	1.61	1.65
NB14	11.5	8.7	248	387	9.4	14.7	5.8	2.5	1.6	55	15.6	2.3	4.3	1.02	0.39	0.041	0.006	1.36	1.39
NB15	10.0	8.5	240	375	8.7	16.5	6.4	3.1	2.2	60	19.2	2.7	4.4	1.04	0.54	0.042	0.010	1.55	1.58

(b) **Physico –chemical characteristics of Dal Lake water during summer season in year 2001 (mg/l).**

Sties	Temperature (^0C)	pH	T.D.S. mg/l	E.C. µs/cm	D.O. mg/l	Ca^{++} mg/l	Mg^{++} mg/l	Na^+ mg/l	K^+ mg/l	HCO_3^- mg/l	Cl^- mg/l	SO_4^{--} mg/l	NO_3^- mg/l	Fe mg/l	Zn mg/l	Mn mg/l	Pb mg/l	Tz^+ µeq/l	Tz^- µeq/l
HZ1	24.7	9.4	209	326	4.7	15.2	6.5	3.7	1.8	60	15.7	2.9	1.7	0.92	0.58	0.041	0.016	1.50	1.48
HZ2	25.4	9.3	208	325	4.9	14.3	5.9	2.9	1.6	46	18.2	3.2	1.4	0.62	0.84	0.039	0.018	1.37	1.33
HZ3	26.9	9.4	212	331	5.1	13.98	6.3	3.8	1.5	55	16.8	3.1	1.5	0.89	0.75	0.040	0.017	1.42	1.45
HZ4	27.0	9.3	215	336	4.5	16.2	7.5	3.9	2.1	57	19.2	3.4	2.1	1.28	0.87	0.059	0.019	1.65	1.68
HZ5	26.7	9.5	200	312	4.6	13.3	5.7	2.7	1.3	52	14.7	2.4	1.8	1.05	0.35	0.058	0.012	1.28	1.32
HZ6	26.4	9.3	2110	328	4.8	12.2	5.2	2.5	1.1	47	13.6	2.2	2.2	1.27	0.27	0.061	0.009	1.17	1.19
HZ7	25.8	9.4	218	341	5.0	16.9	7.6	3.6	1.9	58	17.2	3.3	2.0	1.26	0.86	0.060	0.018	1.67	1.71
HZ8	24.2	9.6	219	342	5.2	15.6	6.7	3.2	1.7	59	15.4	2.5	1.9	1.18	0.42	0.056	0.013	1.51	1.55
HZ9	23.4	9.5	220	344	4.6	13.7	6.1	2.4	1.2	57	12.9	1.8	1.4	0.58	0.15	0.041	0.008	1.32	1.33
HZ10	24.5	9.6	217	339	5.1	15.1	6.2	3.2	1.6	60	14.2	2.3	1.5	0.67	0.40	0.047	0.010	1.44	1.47
HZ11	25.6	9.4	215	336	4.8	13.2	5.4	2.2	1.4	50	13.8	2.1	1.9	1.14	0.21	0.060	0.007	1.23	1.25
HZ12	26.7	9.3	207	323	4.9	17.1	8.1	3.8	2.2	56	20.7	3.2	2.3	1.25	0.79	0.063	0.017	1.74	1.79
HZ13	27.0	9.4	216	337	5.2	14.5	7.3	2.6	1.3	58	17.5	2.8	1.6	0.73	0.62	0.045	0.015	1.48	1.51
HZ14	26.1	9.5	218	341	5.1	12.8	5.5	2.4	1.1	51	12.9	2.4	1.7	0.85	0.36	0.057	0.011	1.22	1.24
HZ15	25.3	9.6	220	344	5.0	17.3	8.2	3.9	2.1	55	21.4	3.4	2.3	1.29	0.87	0.062	0.019	1.76	1.73
BD1	25.4	9.3	210	238	5.0	10.5	4.2	2.1	1.5	34	11.4	1.7	2.1	1.15	0.30	0.050	0.004	1.0	0.92
BD2	24.5	9.4	212	331	4.9	11.3	5.3	2.2	1.3	41	12.3	1.8	2.2	1.18	0.31	0.051	0.005	1.13	1.05
BD3	25.7	9.1	209	327	4.6	12.7	5.5	2.4	1.4	43	13.2	2.3	1.5	0.81	0.81	0.043	0.013	1.22	1.13

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BD4	25.9	8.9	207	323	5.7	10.8	4.3	1.9	1.2	37	11.9	1.5	1.7	0.97	0.26	0.040	0.002	1.0	0.98
BD5	26.2	9.4	206	322	5.4	11.9	5.2	2.3	1.3	39	13.5	2.4	1.4	0.65	0.82	0.038	0.014	1.15	1.07
BD6	24.7	8.9	208	325	4.5	11.6	4.8	1.8	1.5	38	13.7	1.6	1.8	0.94	0.10	0.045	0.003	1.09	1.05
BD7	27.2	9.6	211	330	5.2	12.2	5.7	1.5	1.6	58	14.2	2.2	2.3	1.20	0.76	0.056	0.013	1.18	1.41
BD8	27.5	9.7	213	333	5.4	13.1	5.1	2.2	1.2	40	15.1	2.3	2.4	1.24	0.80	0.057	0.012	1.2	1.11
BD9	26.8	9.5	214	334	4.7	14.9	6.2	2.4	1.4	50	14.7	2.2	2.2	1.22	0.71	0.052	0.012	1.38	1.29
BD10	26.9	9.3	216	337	5.9	13.5	5.6	2.3	1.1	49	15.1	1.9	1.3	0.59	0.42	0.039	0.006	1.26	1.23
BD11	25.6	9.1	215	336	4.8	10.8	4.9	2.1	1.3	39	13.5	2.1	1.5	0.78	0.69	0.041	0.009	1.06	1.04
BD12	26.3	8.9	213	333	4.4	12.4	4.4	1.7	1.4	42	12.6	2.3	2.2	1.16	0.82	0.054	0.014	1.09	1.06
BD13	24.7	9.0	209	327	4.7	13.4	4.6	2.3	1.7	43	12.9	1.7	1.9	0.98	0.29	0.046	0.004	1.19	1.09
BD14	25.3	9.5	208	325	5.6	14.3	4.5	2.1	1.6	46	13.2	2.2	2.3	1.24	0.63	0.055	0.011	1.21	1.17
BD15	27.4	9.3	214	334	5.8	11.2	4.2	1.8	1.5	35	12.3	2.1	1.6	0.93	0.54	0.043	0.008	1.03	0.96
GB1	23.4	9.5	227	355	4.7	13.8	5.5	2.3	1.7	50	15.2	2.7	11.2	1.25	0.25	0.054	0.015	1.28	1.13
GB2	24.7	9.4	228	356	4.9	14.3	6.1	3.2	1.9	55	16.4	3.2	11.3	1.31	0.92	0.056	0.021	1.40	1.43
GB3	23.9	9.3	224	350	5.4	12.9	5.3	2.2	1.5	46	14.7	3.1	10.3	0.95	0.89	0.045	0.020	1.21	1.24
GB4	23.1	9.4	225	351	5.6	11.3	4.7	1.8	1.4	39	13.9	2.6	9.7	0.67	0.38	0.042	0.014	1.06	1.09
GB5	22.7	9.5	227	355	5.5	12.7	5.6	2.3	2.2	48	15.6	2.3	10.4	0.97	0.26	0.047	0.010	1.25	1.28
GB6	22.5	9.6	224	350	4.8	14.5	6.3	3.1	1.6	54	17.2	3.4	11.6	1.34	0.93	0.059	0.021	1.42	1.45
GB7	25.7	9.3	225	351	4.5	13.7	5.2	2.4	2.3	47	16.8	3.2	10.8	1.17	0.91	0.049	0.019	1.27	1.29
GB8	25.4	9.5	224	350	5.0	11.4	4.4	1.6	1.2	37	14.8	2.2	9.8	0.78	0.18	0.044	0.010	1.03	1.07
GB9	24.3	9.3	227	355	5.6	13.9	5.7	2.5	1.1	49	16.2	2.8	11.1	1.17	0.47	0.054	0.016	1.30	1.33

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GB10	22.4	9.4	230	359	5.5	15.2	6.4	3.2	1.3	56	17.5	3.2	12.4	1.39	0.85	0.061	0.020	1.46	1.48
GB11	26.5	9.5	228	356	5.9	13.6	5.3	2.1	1.2	50	14.3	2.9	10.8	1.13	0.48	0.048	0.018	1.24	1.27
GB12	27.8	9.4	229	358	5.7	15.7	6.7	3.3	2.4	59	18.6	3.1	12.9	1.40	0.65	0.063	0.020	1.54	1.58
GB13	26.2	9.6	230	359	4.9	16.4	7.3	3.5	2.1	58	16.7	3.2	13.9	1.42	0.70	0.065	0.021	1.62	1.65
GB14	25.9	9.3	225	351	4.7	14.6	6.2	2.9	1.9	57	15.5	2.8	11.5	1.36	0.55	0.060	0.017	1.41	1.43
GB15	23.7	9.5	225	351	4.5	12.8	5.1	2.6	1.5	51	13.7	2.5	10.2	0.89	0.36	0.046	0.012	1.21	1.24
NB1	26.0	9.6	235	367	5.4	11.2	4.7	2.3	1.6	42	12.2	1.8	5.1	0.89	0.48	0.041	0.008	1.09	1.07
NB2	26.5	9.5	230	359	5.2	12.5	4.3	2.5	1.8	43	12.3	2.1	6.4	1.10	0.70	0.049	0.010	1.13	1.09
NB3	25.9	9.4	222	347	5.5	13.7	4.5	2.4	1.3	44	13.4	2.2	7.6	1.13	0.83	0.054	0.011	1.16	1.15
NB4	26.6	9.5	236	369	4.0	10.4	3.9	2.1	1.4	40	11.2	1.3	4.8	0.74	0.18	0.040	0.004	0.97	0.99
NB5	26.3	9.6	223	348	5.6	11.5	3.8	2.3	1.5	38	13.5	1.7	5.3	0.93	0.40	0.042	0.007	1.02	1.05
NB6	26.2	9.5	233	364	6.7	12.9	4.8	2.6	1.7	47	14.3	2.1	5.5	0.97	0.72	0.044	0.010	1.20	1.23
NB7	26.5	9.4	232	362	5.2	14.6	5.1	2.7	1.2	52	15.2	2.4	8.6	1.18	0.85	0.059	0.013	1.30	1.33
NB8	26.3	9.5	224	350	6.5	11.3	4.2	2.1	1.9	41	12.8	1.6	5.7	0.98	0.28	0.051	0.005	1.05	1.07
NB9	25.9	9.6	230	359	6.9	10.6	4.6	2.2	1.3	42	11.6	1.3	4.9	0.63	0.23	0.039	0.003	1.04	1.06
NB10	27.8	9.5	237	370	7.8	12.2	4.4	2.4	1.4	44	13.8	1.7	6.3	1.08	0.35	0.052	0.007	1.11	1.14
NB11	26.4	9.4	231	361	7.0	10.1	3.7	1.9	1.1	37	11.6	1.2	4.7	0.56	0.13	0.036	0.003	0.92	0.95
NB12	26.4	9.4	229	358	5.4	13.2	4.8	2.3	1.8	51	12.4	2.1	7.9	1.14	0.67	0.032	0.010	1.20	1.23
NB13	26.5	9.5	225	351	7.2	14.4	5.2	2.8	1.7	55	13.5	2.2	8.4	1.17	0.74	0.057	0.012	1.31	1.33
NB14	25.9	9.6	228	356	7.5	11.7	4.3	2.6	1.6	44	14.2	1.9	5.9	1.05	0.65	0.050	0.009	1.09	1.13
NB15	26.0	9.4	229	358	5.3	12.8	4.9	2.7	1.3	45	13.6	2.3	6.7	1.12	0.85	0.052	0.013	1.19	1.23

(c) **Physico –chemical characteristics of Dal Lake water during autumn season in year 2001 (mg/l).**

Sties	Temperature (^0C)	pH	T.D.S. mg/l	E.C. µs/cm	D.O. mg/l	Ca^{++} mg/l	Mg^{++} mg/l	Na^+ mg/l	K^+ mg/l	HCO_3^- mg/l	Cl^- mg/l	SO_4^{--} mg/l	NO_3^- mg/l	Fe mg/l	Zn mg/l	Mn mg/l	Pb mg/l	Tz^+ µeq/l	Tz^- µeq/l
HZ1	22.6	9.4	235	367	4.6	35.3	13.2	5.8	3.1	163	12.8	5.6	2.2	0.94	0.34	0.043	0.010	3.18	3.15
HZ2	23.2	9.3	231	361	4.5	32.6	12.4	5.2	2.9	152	13.6	5.4	1.7	0.73	0.29	0.039	0.009	2.95	2.99
HZ3	25.7	9.3	237	370	6.3	29.4	11.3	5.3	2.4	138	12.7	4.5	1.6	0.68	0.14	0.037	0.005	2.69	2.72
HZ4	24.8	9.5	240	375	5.2	38.3	13.6	5.9	3.2	173	15.4	5.9	1.3	0.46	0.42	0.035	0.012	3.37	3.39
HZ5	20.7	9.4	245	383	5.7	30.2	7.7	5.1	2.5	135	13.3	4.7	1.5	0.58	0.21	0.036	0.007	2.67	2.69
HZ6	21.5	9.3	248	387	6.4	29.7	11.8	5.2	2.4	143	12.5	4.6	2.0	0.90	0.18	0.039	0.006	2.74	2.79
HZ7	25.1	9.3	230	359	7.5	37.4	13.3	6.1	3.1	167	14.2	4.8	2.1	0.92	0.40	0.042	0.011	3.30	3.26
HZ8	19.2	9.4	232	362	8.4	43.1	14.8	6.4	3.4	195	15.8	6.3	2.3	0.97	0.47	0.043	0.015	3.73	3.77
HZ9	20.8	9.5	239	373	4.2	33.6	12.5	5.4	2.8	156	13.8	5.5	2.2	0.95	0.32	0.041	0.010	3.01	3.05
HZ10	26.3	9.5	246	384	7.8	40.2	14.3	6.2	3.3	182	15.6	6.1	1.2	0.38	0.46	0.031	0.013	3.54	3.55
HZ11	19.9	9.4	252	394	9.2	26.8	10.8	5.2	2.2	129	12.4	4.1	2.3	0.96	0.12	0.042	0.004	2.51	2.55
HZ12	23.4	9.4	255	398	9.3	37.5	12.9	5.6	3.2	168	14.7	5.6	1.9	0.83	0.38	0.041	0.010	3.26	3.29
HZ13	25.8	9.5	253	395	8.9	39.4	13.1	6.1	3.3	176	13.9	6.0	2.1	0.94	0.45	0.042	0.012	3.39	3.41
HZ14	26.1	9.4	251	395	9.1	30.5	11.9	5.3	2.4	144	12.9	4.8	1.8	0.78	0.25	0.040	0.008	2.79	2.82
HZ15	24.2	9.3	249	389	6.8	41.3	14.4	6.3	3.4	189	14.9	6.2	1.6	0.64	0.48	0.036	0.014	3.61	3.65
BD1	20.4	9.1	231	361	6.9	23.4	8.4	4.8	2.3	105	12.6	2.9	1.8	0.89	0.28	0.032	0.005	2.13	2.15
BD2	21.7	9.2	229	358	7.4	20.6	7.2	4.5	2.1	90	13.4	2.7	1.7	0.85	0.29	0.030	0.003	1.87	1.91
BD3	23.5	9.1	225	351	7.5	24.5	9.5	5.3	2.5	113	14.2	3.3	1.9	0.91	0.42	0.033	0.008	2.30	2.33

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BD4	22.8	9.3	236	369	6.8	18.7	6.2	4.2	2.1	84	10.5	2.2	1.6	0.83	0.11	0.029	0.001	1.68	2.71
BD5	19.6	9.3	237	370	6.9	19.6	6.5	4.3	2.2	87	11.3	2.3	1.5	0.75	0.13	0.028	0.001	1.76	1.79
BD6	20.2	9.2	235	367	7.1	22.5	7.4	4.7	2.3	99	12.1	2.8	1.7	0.79	0.26	0.032	0.004	1.99	2.03
BD7	25.3	9.2	229	358	7.4	24.3	9.2	5.2	2.4	114	13.2	3.2	2.1	0.93	0.42	0.035	0.008	2.26	2.29
BD8	24.7	9.1	234	366	7.3	23.5	8.2	4.4	2.1	101	14.1	3.0	2.1	0.92	0.41	0.036	0.006	2.09	2.12
BD9	26.2	9.2	230	359	7.2	22.9	7.8	4.6	2.2	102	12.2	2.9	1.5	0.73	0.35	0.030	0.005	2.04	2.07
BD10	27.4	9.1	223	348	6.8	24.1	9.1	5.1	2.4	112	12.7	3.1	2.2	0.95	0.40	0.036	0.007	2.23	2.28
BD11	27.6	9.2	216	337	7.5	23.6	8.7	5.0	2.3	107	13.9	2.8	1.4	0.62	0.27	0.029	0.004	2.17	2.21
BD12	26.1	9.3	205	320	7.8	20.3	7.1	4.0	2.0	89	12.5	2.3	1.1	0.32	0.10	0.028	0.002	1.82	1.87
BD13	27.3	9.2	210	328	7.6	21.9	7.3	4.1	2.1	91	14.0	2.8	1.2	0.46	0.30	0.029	0.04	1.92	1.95
BD14	27.2	9.3	215	336	7.7	20.4	7.0	4.2	2.3	92	13.2	2.4	1.5	0.71	0.17	0.031	0.002	1.83	1.92
BD15	25.9	9.2	227	354	7.5	24.2	8.9	5.1	2.4	104	14.7	2.9	1.3	0.53	0.37	0.030	0.005	2.22	2.18
GB1	20.1	9.0	240	375	5.6	33.6	13.4	5.3	3.2	157	13.5	4.7	7.2	0.74	0.28	0.036	0.002	3.09	3.05
GB2	21.7	8.9	245	383	5.7	31.7	11.3	5.2	2.9	145	13.2	4.5	6.9	0.59	0.19	0.032	0.001	2.81	2.84
GB3	19.3	9.1	238	372	6.2	30.5	10.5	4.8	2.5	135	12.9	4.6	7.1	0.69	0.24	0.034	0.002	2.66	2.76
GB4	24.5	8.8	254	397	6.7	29.2	11.8	5.1	2.8	140	13.0	4.5	8.2	1.10	0.18	0.043	0.001	2.72	2.75
GB5	25.7	8.9	239	373	5.4	27.3	10.7	4.9	2.6	128	12.7	4.2	6.9	0.61	0.15	0.031	0.001	2.52	2.55
GB6	23.6	8.9	252	394	6.9	38.4	13.4	5.2	2.7	172	14.4	5.6	8.2	1.11	0.55	0.046	0.007	3.31	3.34
GB7	20.1	9.2	248	387	6.8	41.3	14.2	5.6	3.2	184	15.4	5.8	8.3	1.12	0.57	0.044	0.007	3.55	3.58
GB8	22.9	9.1	237	370	5.8	37.2	12.6	5.2	2.7	165	14.2	5.5	7.9	0.91	0.51	0.042	0.005	3.19	3.22
GB9	19.0	8.9	250	390	6.3	35.6	11.9	5.0	2.5	159	13.3	5.0	7.3	0.78	0.30	0.038	0.004	3.04	3.08
GB10	19.9	9.0	252	394	7.2	40.3	14.1	5.5	3.1	180	15.2	5.7	7.8	0.83	0.56	0.042	0.007	3.49	3.50

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GB11	25.4	9.1	249	389	6.5	39.4	13.5	5.3	3.0	175	14.7	5.5	7.4	0.72	0.48	0.040	0.006	3.38	3.40
GB12	24.3	9.0	248	387	7.3	37.1	12.3	5.1	2.6	164	13.6	5.3	8.3	1.11	0.45	0.045	0.005	3.15.0	3.18
GB13	26.5	8.9	259	405	5.9	40.3	13.9	5.4	3.1	181	15.3	5.6	8.4	1.12	0.53	0.047	0.006	3 3.47	3.50
GB14	26.7	8.9	236	369	5.7	35.9	12.2	5.0	2.5	160	14.1	5.2	8.1	1.08	0.39	0.045	0.004	3.08	3.11
GB15	25.7	9.2	258	403	6.1	34.6	11.7	5.2	2.8	152	13.2	4.9	7.8	0.90	0.32	0.041	0.003	2.99	2.97
NB1	22.5	9.4	230	359	6.2	22.3	8.2	4.1	2.2	100	13.1	2.5	3.5	0.99	0.21	0.036	0.003	2.02	2.06
NB2	19.6	9.2	235	367	7.2	18.5	7.5	3.8	2.0	88	10.5	2.3	3.4	0.97	0.14	0.035	0.002	1.76	1.79
NB3	18.5	9.3	202	316	5.4	23.6	8.4	4.5	2.4	104	14.2	2.8	3.1	0.78	0.36	0.031	0.006	2.13	2.16
NB4	22.0	9.0	235	367	6.3	24.4	8.6	4.7	2.5	110	13.3	3.0	3.7	1.04	0.39	0.037	0.007	2.19	2.24
NB5	23.5	9.5	225	351	7.3	20.5	7.6	3.9	2.1	94	11.8	2.3	3.0	0.67	0.15	0.032	0.001	1.87	1.92
NB6	19.0	9.3	230	359	6.8	22.1	8.0	4.1	2.3	99	13.0	2.6	3.6	1.02	0.32	0.037	0.004	2.00	2.05
NB7	20.5	9.3	220	344	6.5	21.2	7.8	4.0	2.0	91	14.9	2.4	2.9	0.52	0.16	0.029	0.002	1.92	1.97
NB8	21.6	9.2	235	367	7.4	19.7	7.6	3.9	2.1	89	12.7	2.3	3.5	0.98	0.12	0.037	0.002	1.83	1.85
NB9	23.4	9.4	218	341	7.5	23.9	8.5	4.6	2.5	111	11.6	2.9	3.4	0.95	0.35	0.036	0.006	2.16	2.19
NB10	25.3	9.4	246	384	6.1	22.6	8.2	4.2	2.3	101	13.5	2.7	3.2	0.92	0.31	0.033	0.005	2.04	2.09
NB11	22.5	9.5	237	370	7.6	24.5	8.7	4.8	2.6	112	12.2	3.1	3.6	1.03	0.38	0.038	0.007	2.21	2.24
NB12	19.0	9.5	215	336	7.9	18.2	7.54	4.0	2.2	84	10.3	2.1	3.3	0.84	0.07	0.034	0.001	1.75	1.71
NB13	19.5	9.4	230	359	6.8	23.4	8.3	4.3	2.3	102	14.3	2.8	3.0	0.69	0.37	0.033	0.005	2.10	2.13
NB14	18.5	9.2	245	383	6.7	21.7	7.9	4.0	2.0	98	12.0	2.5	3.1	0.75	0.25	0.035	0.003	1.96	1.99
NB15	25.0	9.4	240	375	7.6	20.9	7.7	4.1	2.1	92	13.4	2.4	2.9	0.46	0.23	0.030	0.002	1.91	1.94

(d) **Physico –chemical characteristics of Dal Lake water during winter season in year 2001 (mg/l).**

Sties	Temperature (^0C)	pH	T.D.S. mg/l	E.C. µs/cm	D.O. mg/l	Ca^{++} mg/l	Mg^{++} mg/l	Na^+ mg/l	K^+ mg/l	HCO_3^- mg/l	Cl^- mg/l	SO_4^{--} Mg/l	NO_3^- mg/l	Fe mg/l	Zn mg/l	Mn mg/l	Pb mg/l	Tz^+ µeq/l	Tz^- µeq/l
HZ1	-1.2	8.4	245	383	10.4	38.6	15.7	6.5	3.3	188	12.8	4.8	1.5	0.39	0.26	0.030	0.008	3.58	3.54
HZ2	-1.5	8.7	243	380	9.9	34.4	15.3	5.9	3.2	168	14.6	5.9	2.2	0.71	0.31	0.034	0.009	3.33	3.29
HZ3	-2.0	8.0	248	387	11.4	32.3	14.7	6.5	3.1	160	13.5	5.6	1.6	0.45	0.28	0.029	0.010	3.18	3.12
HZ4	1.7	8.9	241	376	10.7	41.7	15.9	5.8	3.7	183	15.4	6.2	2.1	0.63	0.42	0.032	0.011	3.74	3.56
HZ5	2.1	8.6	242	378	9.8	29.4	12.6	6.1	2.6	146	12.5	4.7	1.7	0.59	0.20	0.031	0.007	2.84	2.85
HZ6	1.9	8.8	249	389	9.9	26.2	11.7	5.6	2.3	127	11.3	4.0	1.1	0.24	0.12	0.027	0.004	2.53	2.49
HZ7	2.4	8.0	240	375	11.4	42.9	16.1	6.2	3.6	196	13.2	6.3	1.6	0.42	0.40	0.028	0.011	3.83	3.72
HZ8	2.7	8.2	246	384	11.7	39.6	11.5	5.8	3.8	174	12.5	4.5	1.8	0.60	0.19	0.031	0.006	3.27	3.31
HZ9	-1.9	8.1	250	391	12.2	31.7	10.1	5.7	3.2	137	10.5	3.9	2.1	0.65	0.10	0.033	0.003	2.74	2.62
HZ10	2.8	8.3	249	389	12.4	37.4	16.3	6.3	3.4	187	12.6	4.3	2.2	0.69	0.17	0.034	0.006	3.49	3.51
HZ11	3.7	8.5	251	392	11.9	28.9	14.6	6.5	3.1	159	11.8	4.1	1.3	0.31	0.14	0.028	0.005	3.01	2.02
HZ12	3.8	8.2	250	391	11.7	43.6	15.4	6.4	3.6	198	14.5	6.4	1.4	0.35	0.41	0.029	0.012	3.81	3.79
HZ13	2.4	8.9	247	386	12.3	35.4	13.5	6.2	3.2	167	13.8	5.7	1.7	0.56	0.29	0.030	0.009	3.23	3.25
HZ14	-2.0	8.2	248	387	12.4	27.9	11.7	5.5	2.9	126	13.4	5.2	1.5	0.40	0.25	0.028	0.009	2.67	3.56
HZ15	1.5	8.1	242	378	10.6	45.7	16.2	6.3	3.8	201	15.2	6.7	2.2	0.72	0.42	0.033	0.012	3.98	3.87
BD1	-4.2	8.5	230	359	10.2	20.2	7.3	4.4	2.3	96	7.5	2.5	1.0	0.17	0.09	0.024	0.001	1.86	1.84
BD2	-3.4	8.7	235	367	11.5	21.3	8.2	4.6	2.2	101	8.1	2.7	1.2	0.19	0.12	0.025	0.001	1.99	1.95
BD3	1.2	8.2	242	378	9.3	22.8	8.9	5.1	2.6	111	8.7	3.2	1.4	0.21	0.32	0.028	0.005	2.16	2.13
BD4	-4.5	8.4	241	376	9.4	20.9	7.8	4.6	2.1	103	7.9	2.6	1.3	0.20	0.09	0.026	0.001	1.94	1.98

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BD5	-5.6	8.3	225	351	8.8	23.5	9.1	5.2	2.4	115	9.5	3.1	1.5	0.23	0.25	0.027	0.004	2.21	2.23
BD6	-5.7	8.7	228	356	9.1	21.7	8.5	4.7	2.3	106	8.2	2.9	1.1	0.16	0.14	0.025	0.002	2.05	2.03
BD7	3.5	8.5	244	381	10.5	22.3	8.6	4.8	2.4	106	8.5	3.1	1.2	0.18	0.36	0.029	0.003	2.09	2.05
BD8	4.7	8.9	230	359	11.8	24.3	9.2	5.3	2.3	116	9.2	3.2	1.7	0.28	0.37	0.030	0.004	2.26	2.24
BD9	5.8	8.8	236	369	10.7	26.7	10.5	5.6	2.5	128	10.3	2.9	2.2	0.34	0.18	0.036	0.002	2.50	2.47
BD10	6.3	8.2	238	372	12.1	25.7	9.1	5.3	2.4	118	9.7	3.3	2.1	0.32	0.38	0.034	0.006	2.32	2.29
BD11	6.5	8.4	248	387	12.2	23.9	9.2	5.3	2.6	118	9.4	3.2	1.5	0.25	0.35	0.029	0.005	2.25	2.28
BD12	-2.2	8.7	252	394	9.1	22.5	8.7	4.9	2.5	108	8.7	3.1	1.4	0.26	0.28	0.028	0.003	2.12	2.09
BD13	-3.5	8.9	250	391	10.6	24.9	9.4	5.4	2.7	123	9.3	3.4	1.9	0.30	0.39	0.033	0.006	2.32	2.35
BD14	5.4	8.5	247	386	11.5	25.2	9.2	5.2	2.6	122	9.8	3.2	2.0	0.31	0.36	0.035	0.004	2.31	2.34
BD15	6.1	8.3	240	375	12.0	21.7	8.5	4.8	2.4	104	8.4	2.9	1.2	0.18	0.21	0.027	0.002	2.05	2.01
GB1	-3.2	7.9	240	375	9.5	30.4	11.9	5.2	2.6	141	12.3	4.5	5.0	0.45	0.15	0.032	0.002	2.79	0.75
GB2	-4.8	8.0	243	380	10.2	33.8	12.7	5.4	2.9	158	12.8	5.3	5.2	0.58	0.31	0.033	0.006	3.04	3.06
GB3	-5.2	8.3	239	373	8.9	28.2	10.4	5.2	2.7	129	11.4	5.2	4.6	0.34	0.29	0.029	0.007	2.56	2.54
GB4	2.3	7.5	235	367	8.7	25.6	10.3	5.3	3.2	123	10.3	4.7	4.7	0.32	0.19	0.030	0.003	2.44	2.41
GB5	1.5	8.1	245	383	9.4	29.4	11.5	5.4	3.1	138	11.7	4.5	4.8	0.37	0.13	0.031	0.002	2.73	2.69
GB6	3.4	8.4	248	387	9.9	42.2	15.6	5.9	2.8	193	13.9	6.1	6.3	0.75	0.44	0.036	0.010	3.72	3.68
GB7	2.0	8.5	261	408	10.8	39.7	14.7	5.7	3.3	168	13.4	5.7	5.8	0.69	0.40	0.034	0.008	3.52	3.55
GB8	-1.7	8.1	250	391	11.4	32.5	13.5	5.3	2.5	158	12.6	4.9	4.6	0.36	0.21	0.029	0.005	3.03	3.05
GB9	-4.9	7.9	253	395	12.0	35.6	14.2	5.4	2.4	168	12.7	5.1	4.9	0.47	0.29	0.031	0.006	3.24	3.22
GB10	-5.5	7.4	256	400	11.4	38.4	14.4	5.5	2.3	176	12.9	5.4	5.6	0.64	0.38	0.032	0.008	3.40	3.37
GB11	-2.1	8.2	260	406	10.7	36.7	12.7	5.2	2.2	163	11.8	5.3	5.2	0.59	0.32	0.029	0.007	3.16	3.12

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GB12	1.9	8.6	258	403	8.8	40.3	15.2	6.4	3.2	183	5.4	5.9	6.2	0.72	0.42	0.035	0.009	3.62	3.55
GB13	2.3	8.5	262	409	9.3	43.7	15.9	6.2	3.1	198	14.6	6.2	6.4	0.74	0.45	0.037	0.010	3.84	3.79
GB14	4.3	8.2	269	420	10.1	37.4	14.3	5.6	2.7	179	12.4	5.2	5.3	0.60	0.28	0.033	0.007	3.36	3.39
GB15	4.2	8.7	266	416	11.8	31.6	11.8	6.1	2.9	148	11.9	4.8	5.1	0.56	0.23	0.031	0.004	2.89	2.87
NB1	2.5	8.3	260	406	9.4	21.9	8.5	4.6	2.3	106	8.1	2.6	2.8	0.20	0.17	0.030	0.002	2.05	2.02
NB2	4.2	8.2	235	367	9.6	22.7	8.8	4.9	2.7	110	8.7	3.1	2.7	0.18	0.25	0.029	0.002	2.14	2.11
NB3	4.5	8.0	230	359	8.6	24.5	8.6	4.7	2.4	115	9.5	3.2	3.8	0.27	0.28	0.031	0.003	2.20	2.21
NB4	4.3	8.5	255	398	10.5	20.6	7.5	4.3	2.1	101	7.6	2.3	2.9	0.21	0.06	0.030	0.003	1.89	2.92
NB5	4.2	8.3	234	366	10.3	23.2	8.3	4.6	2.4	109	8.2	2.9	3.7	0.29	0.21	0.032	0.002	2.10	2.07
NB6	1.5	8.6	243	380	8.7	25.4	8.9	4.8	2.7	119	9.8	3.3	4.5	0.31	0.31	0.034	0.004	2.28	2.30
NB7	3.5	8.2	235	367	10.5	26.2	10.3	5.2	2.4	125	10.2	3.7	5.2	0.36	0.32	0.039	0.004	2.44	2.42
NB8	-2.5	8.5	242	378	11.2	22.5	8.6	4.7	2.6	107	8.5	2.9	3.4	0.28	0.22	0.030	0.002	2.10	2.06
NB9	2.5	8.3	257	401	10.5	21.3	8.3	4.4	2.3	104	7.9	2.5	2.6	0.19	0.13	0.028	0.002	2.00	1.98
NB10	5.0	8.7	237	370	11.0	22.1	8.5	4.7	2.4	110	8.5	2.9	3.3	0.25	0.20	0.031	0.002	2.07	2.10
NB11	3.5	8.5	236	369	8.9	20.1	7.2	4.2	2.1	97	7.3	2.4	2.5	0.18	0.09	0.026	0.002	1.83	1.85
NB12	4.5	8.4	267	417	10.3	23.7	8.6	4.8	2.5	115	8.6	3.1	3.5	0.28	0.24	0.033	0.003	2.16	2.19
NB13	-3.0	8.2	252	394	8.9	25.6	9.4	5.3	2.7	120	9.5	3.3	4.7	0.34	0.31	0.036	0.004	2.35	2.32
NB14	4.0	8.3	257	401	10.7	24.3	8.8	4.9	2.6	116	9.7	3.2	4.2	0.31	0.30	0.033	0.003	2.22	2.24
NB15	4.1	8.5	260	406	8.8	25.3	9.2	5.1	2.5	119	9.6	3.3	5.0	0.37	0.32	0.038	0.004	2.31	2.29